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Editor: TREVOR I. WILLIAMS, M.A., B.Sc., D.Phil., F.R.I.C.
Editorial Assistants: G. N. J. BECK, B.Sc., A.M.I.E.E. (*Foreign Editions*)
W. A. OSMAN, B.Sc., M.Sc., A.R.C.S.

Imperial Chemical Industries Limited, Millbank, London, S.W.1
Communications to the Editor should be addressed to North Block, Thames House, Millbank, London, S.W.1

The exploration of space

The great acceleration of scientific discovery and its application during the last two decades has created many problems, not least of which is to foresee and prepare for the far-reaching social consequences. That science is still widely regarded with suspicion, as being on balance more likely to destroy mankind than to bring great benefits, is in large measure due to failure to prepare the general public for developments that the responsible authorities should see to be imminent and inevitable. Neglect of this important aspect of policy is nowhere more serious than in relation to the exploration of space. The launching of the first artificial satellite by the Russians in October 1957 took the world almost entirely unawares, and provoked, beside much thoughtful comment, a flood of sensational and ill-informed speculation about its significance. Within less than two years progress in space exploration has been remarkable. Not only have more artificial satellites been launched, both by Russia and by the United States, but projectiles have been sent beyond the Moon to become permanent new planets. Preparations are known to be far advanced towards launching a man-carrying rocket into orbit round the Earth. It is clear that space exploration, long looked upon merely as the fantasy of writers of fiction, is on the verge of achievement. A new age of exploration is imminent whose full consequences cannot be foretold but can scarcely be less than those of the great voyages of discovery which for the first time made whole new continents open to western civilization.

That these exciting developments should widely be greeted not merely with apathy but with opposition is not altogether surprising, for there are many historical parallels. Many of the long sea voyages that shaped the modern pattern of civilization were looked upon in their day as acts of folly, and those who made them not only suffered much ill-rewarded hardship, or even punishment, but often had the greatest difficulty in obtaining the necessary support. Only when the enormous potential value of the new discoveries became apparent was the support forthcoming that would so much have eased the burden of the pioneers. Nevertheless, while fear of the unknown is a widely ingrained human quality, determination to conquer it regardless of the hazards is equally ingrained in a small minority. It is thanks to such determination in individuals that the principal territories of the earth have been explored, in spite of great difficulties and dangers, and the extent of the civilized world greatly extended. In this respect, however, the analogy between terrestrial exploration and that of space breaks down. When all else failed, terrestrial exploration could be sponsored by private groups and the support of governments could follow later. In the exploration of space precisely the reverse sequence of events seems certain. Because of its enormous initial cost, and of the stragetic considerations, the pioneer attempts must be government-sponsored if they are to be made at all. Later, perhaps, private enterprise may enter the field, just as it has done in the development of atomic power, originally the strict preserve of governments.

In considering the exploration of space, comparison with terrestrial exploration is inevitable, for no other can be made. Features common to both are certainly apparent. Against terrestrial exploration, for example, it was argued that it was pointless to seek remote and probably barren new lands, at the furthest limits of the then available means of transport, when there was still room for expansion and development at home. Similarly, it is now argued, often at a high policy level, that there is no point in venturing into space when so much research remains to be done in existing fields. A further reason for doubts about the value of space exploration is, of course, that it is linked with the unending struggle between nations to establish military supremacy. The launching of satellites is a by-product of the construction of long-range military missiles. This is universally known, and nobody supposes that the exploration of space springs in the first instance from a disinterested desire to extend scientific knowledge and better the lot of mankind. Nevertheless, the growing realization of the immense value of atomic power, despite the fact that it originally became available only through the manufacture of atomic bombs, encourages the hope that the origins of space exploration will in time be overlooked.

What are the merits of undertaking space exploration that can commend it to the governments of the great powers, which at present are the only bodies commanding sufficient resources to make it possible? First and foremost, of course, is the possibility of acquiring a wealth of valuable new scientific knowledge: the results achieved within a remarkably short time by the first satellites give convincing proof that this is not

mere optimism. Hitherto we have been obliged to look into space through two narrow windows, corresponding to the wavelength of light and of radio waves. With the aid of instruments located beyond the confines of the atmosphere we can have a far less restricted view of the universe. It is impossible, in the nature of things, to predict what a venture into the unknown will bring forth, but there is ample historical evidence that in the long run pure research in a wide field yields high practical dividends. At least two major fields of applied science—meteorology and radio communication—are clearly likely to benefit enormously from increased knowledge not only of the upper atmosphere but of the newly discovered regions of high radiation intensity that lie above it. The vast economic value of accurate weather forecasting on a world-wide scale needs no emphasis: the possibility of achieving this, and perhaps also of gaining some measure of control over the weather, would alone justify very heavy capital expenditure. Ability to photograph weather conditions over vast areas would in itself be of great value, and already some success in this has been reported. Similarly, there would be great practical value in improving the quality and reliability of long-distance radio communication. These are well known to depend very much on solar conditions, and the recent photographing of the Sun's disk from a point far above the Earth's atmosphere is an indication of the way in which space exploration can advance the study of solar physics. Clearly, too, long-distance flying might be greatly speeded up if the greater part of the flight could be made above the atmosphere rather than through it: the development of the necessary materials and techniques could scarcely fail to be valuable for many other purposes.

Outer space provides experimental conditions not attainable in the laboratory, and much new knowledge in the field of astrophysics and atomic physics can certainly be expected to be gained. In the biological and biochemical fields the prospects are enormously interesting. It is hard to believe that life is unique to the Earth, and it may well be that even within the solar system—on Mars or Venus, for example—there exist living organisms, if only simple ones, whose vital processes are quite different from those of terrestrial plants and animals. That this is not an extravagant flight of fancy, but a serious consideration, is apparent from the fact that international agreement is already being sought on the organization of space flight so that the scientific results to be obtained will not be made uncertain by the unintentional introduction of biological material derived from the Earth.

Apart from such considerations, which follow fairly obviously from the trend of current achievements, space exploration clearly also has the possibility of opening up fields of knowledge whose very existence is at present unsuspected. Newton took a modest view of his own remarkable achievements: 'I seem to have been only like a boy, playing on the seashore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, while the great ocean of truth lay all undiscovered before me.' Science has progressed remarkably since Newton's day, but none can doubt that the ocean still remains largely uncharted.

The exploration of space clearly ought to be an international venture, and the International Council of Scientific Unions has already performed a valuable service by establishing the International Committee on Space Research (Cospar), but, while there is already some degree of collaboration, it is evident that in present circumstances rivalry between nations is inevitable. It is to be expected, therefore, that there will be only limited publication of results achieved, and that only those nations that have themselves some worth-while contribution to make will benefit from the experience of others. In time this situation may change—as it has done in the field of atomic energy—but to wait for it to do so is to allow others to gain what is likely to prove a commanding lead. At present, space exploration is pre-eminently a Russian and American field. If other nations allow it to remain so, they run a grave risk of having no standing in what may prove one of the most fruitful fields of modern research. Manned flights into space clearly raise very great practical problems that are still far from being solved, but within the last two years it has been demonstrated beyond argument that much can be learned from instrument-carrying devices. The usefulness of such devices will increase as advances are made in instrumentation. Within this narrower, but still exceedingly important, field it is surely possible for research to be more truly international than it is at present. The recent announcement of a British programme for the design and construction of instruments to be carried in the satellites of other nations is a welcome first step in this direction. Further plans for an all-British effort in space exploration are under consideration, and it is very much to be hoped that they will soon develop and be put into effect.

Galactic structure and the 21-centimetre microwave line

H. C. VAN DE HULST

It is a tribute to the spirit of the Dutch people that one of the most fruitful lines of modern astronomical research, the study of the 21-cm hydrogen line, began in Holland in 1944, when the country was suffering great privation and was almost completely cut off from the rest of the world. One of the distinguished pioneers in this field, who predicted from theoretical considerations the occurrence of the 21-cm hydrogen line, traces here the rapid progress that has been made since the war and discusses the light it throws on galactic structure.

The existence of electromagnetic waves was predicted by Clark Maxwell several years before they were produced experimentally by Hughes and by Hertz. The history of radio-astronomy shows a parallel, for the possibility of observing extra-terrestrial radio waves was considered more than thirty years before successful observations were made.

Marconi first sent a wireless signal over a distance of several kilometres in 1896. In the same year Wilsing and Scheiner attempted to receive radio signals from the Sun; their experiments were based on the correct assumption that the solar spectrum should extend through the infra-red into the radio domain.

The first detection of radio waves from outside the Earth came from an unexpected source. In 1930 Jansky detected radio waves emanating not from the Sun but from the Milky Way. Retrospectively this seems a startling discovery, but at the time astronomers paid no attention to it. Nearly ten years later, when more detailed results had been obtained by Reber, two astrophysicists, Henyey and Keenan, made a first attempt to explain this radiation. Their results were published in the 'Astrophysical Journal', and the astronomical world began gradually to appreciate the great possibilities of this field.

The expansion of radio-astronomy in the subsequent twenty years was tremendous. It has not remained an interesting annexe to astronomy, taken care of by a few specialists, but has penetrated deeply into many subjects of major importance in astronomy. In a few fields it has been found to be more useful than optical astronomy. The present situation is well illustrated by the fact that an up-to-date introductory course in general astronomy now has to refer to radio-astronomical findings in at least a dozen fields, such as the velocity and statistics of meteors, the temperatures of the planets, the solar corona, solar flares, gaseous nebulae and ionized regions of interstellar space, neutral clouds in interstellar space, the envelopes of supernovae, the structure and rotation of our Galaxy, the rotation and mass of other stellar systems (spiral nebulae), and the expanding universe.

The idea of investigating galactic structure by means of observations of neutral hydrogen originated in 1944, when Holland was cut off from normal communications with other countries and university life was disrupted. For all we in Holland knew, radio-astronomy was still exclusively an American affair, although actually Britain and Australia had already started their impressive work in this field. Oort, who had done much research on galactic structure, asked me to study, and to review at a colloquium, the theory behind Reber's observations. He also told me to look for spectral lines in this domain, as such lines would permit the measurement of velocities by the Doppler effect and thus give a very important clue for locating the origin of the radiation.

At this point we should recall the normal methods for determining distances in astronomy. The invariable predicament of the astronomer investigating galactic structure is that the distances of his objects are either unknown or poorly known. The most common types of stars in the Galaxy are distributed in a flat disk having a thickness of a few hundred parsecs and a radius of the order of 15 000 parsecs[1]. The Sun is located somewhere near the plane of symmetry of the disk, at 8000 parsecs from the centre. Looking from this isolated observing post, we can obtain reliable determinations of the distances of all stars nearer than 50

[1] 1 parsec = $3{\cdot}08 \times 10^{18}$ cm ≈ 3 light-years.

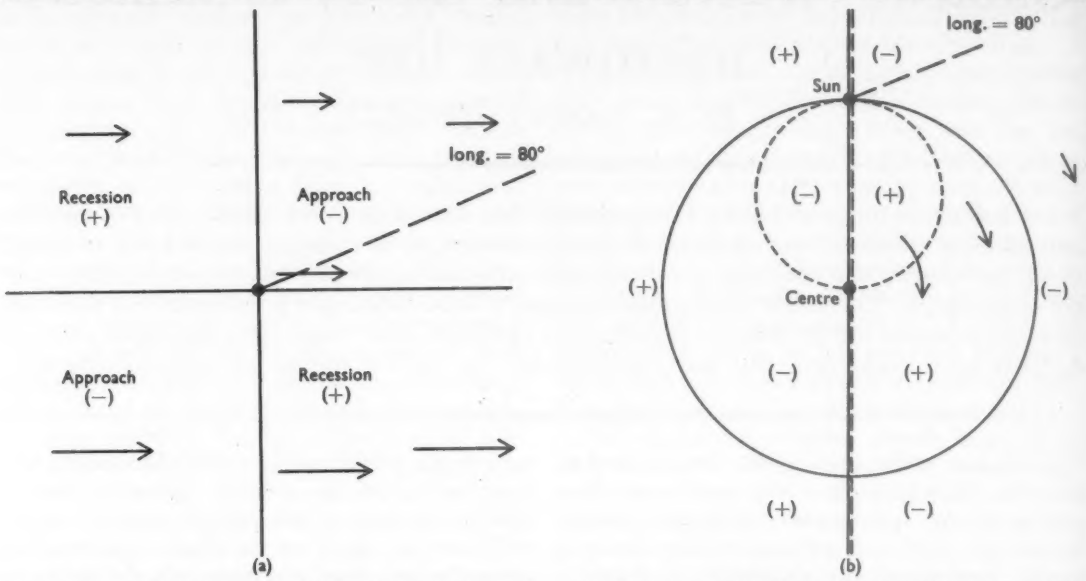


FIGURE 1 – *The phenomenon of differential galactic rotation.* (a) *The situation in the vicinity of the Sun: photographic and photoelectric observations do not penetrate beyond this region.* (b) *The situation over the entire galactic plane. This overall view is displayed only by the 21-cm line. In both diagrams + signs indicate systematic velocities of recession, − signs, systematic velocities of approach. The solid lines represent zero velocity. The distance estimate fails on the the broken line and circle, where the first-order change of velocity with distance is* 0.

parsecs by triangulation, based on the diameter of the Earth's annual orbit, but these stars are an almost negligible fraction of the entire Galaxy. However, observations of them provide the data for calibrating secondary distance standards that may be used farther out. Many of these are based on statistical studies of stellar motions.

A powerful method, applicable to stars more than 500 parsecs distant from us, is given by the observation of differential galactic rotation. With some exceptions, the stars in any local volume seem to move at random. Their speeds with respect to the centre of gravity of the group are of the order of 10 or 20 km/sec; the Sun is no exception and has a speed of 18 km/sec relative to the centre of gravity of all stars in our vicinity. However, on a galactic scale all these stars move together: the centre of gravity of the group describes a circular orbit around the centre of the Galaxy, each individual star moving in a somewhat excentric orbit. The actual speeds are high—the stars near the Sun have an orbital speed of 220 km/sec and an orbital period of 230 million years—although this can be detected only from the study of other groups of stars at considerable distances.

The angular velocity of the stars due to the rotation of the Galaxy decreases with distance from the centre, as is illustrated by the lengths of the arrows in figures 1*a* and 1*b*. If the broken line in figure 1*a* represents the direction of motion of the Sun, it is clear that the Sun will tend to overtake the stars in the top right quadrant and will approach them. Similarly the stars in the bottom left quadrant will tend to catch up the Sun and will also approach it. The stars in the other two quadrants, on the other hand, will be found to recede from the Sun. Observation confirms this. The relative speeds increase with the distance and can be measured by the Doppler effect. Hence they can be used for determining distances. A severe limitation of this method is that at distances of more than 2000 parsecs from the Sun optical observations of stars near the galactic plane become extremely difficult, because most objects are partially or completely obscured by interstellar absorption. Moreover, the linear approximation fails. The situation then obtaining is illustrated in figure 1*b*.

The same technique can be used in radio-astronomy. In the search for a suitable spectral line, one fine-spectrum possibility suggested itself. This is the line corresponding to a transition between the two levels into which the ground level of the hydrogen atom is split by the effect of hyperfine structure. In popular terms, the electron and the proton that make up the hydrogen atom may

be looked upon as permanent magnets; the line is emitted when they switch from parallel to anti-parallel. The wavelength of this line, 21·2 cm, is convenient for modern techniques. In 1945, however, there were still technical difficulties in working at so short a wavelength, and, although the first attempts were made soon after that time, the actual detection of the line came only in 1951, with the almost simultaneous discoveries by Ewen in the United States, by Muller in Holland, and by Christiansen and Hindman in Australia. Since then there has been a steady period of data-collecting in Holland, in Australia, and in other countries.

THE TECHNIQUE OF OBSERVATION

In principle, the task of completely observing the 21-cm line is to make a map of the intensity as a function of three variables: the frequency (convertible into velocity) and two celestial co-ordinates. The equipment available for the purpose has improved strikingly during the last few years. Thus, to take further examples from Holland, there is an enormous difference between the equipment at Kootwijk in 1952 and that used at Dwingeloo in 1959. The apparatus first used was an old German radar mirror with an elliptical antenna beam of $2° \times 3°$. The telescope was cranked by hand, and laborious methods were used to check the frequency and keep the oscillators locked in. Now we have a well-designed 25-metre mirror with a round antenna beam of 0·57° diameter, and dial setting of the co-ordinates either for following a fixed position or for scans, and automatic frequency markers; a wide choice of time constants and bandwidths is now possible. An even more important improvement is in the sensitivity and stability of the receiver. A convenient unit in which to express the brightness of extended regions of the sky in radio-astronomy is the degree Kelvin (°K). A black body of the temperature thus expressed would have the same brightness, at a given frequency, as the actual object observed. When the 21-cm line was first observed, the maximum line intensity (about 100°K) was quite difficult to detect. For some years spurious fluctuations and jumps of the order of 5–10°K remained common. The zero of a modern receiver, however, drifts less than 1°K over a period of many days. The final accuracy seems to depend mainly on the bandwidth and on the time one can afford to average the receiver noise. In the present investigations on extra-galactic systems, where the intensity is lowest, an accuracy of 0·15°K is regularly attained.

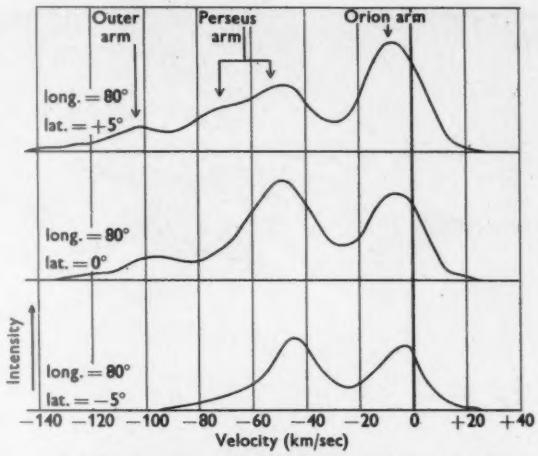


FIGURE 2 – *Line profiles for three points in Cassiopeia and Cepheus. Each profile is a plot of intensity against Doppler velocity. Their common longitude is* 80° *(broken line in figure* 1*). The middle point is in the galactic plane; the others have latitudes* 5° *above and below the galactic plane. Note different dependence on latitude in the three arms.*

The scans can be made in many ways, and the choice depends on practical considerations. Most often the telescope follows the daily motion of a point in the sky and a gradual scan in frequency is made. The result is a line profile, entirely comparable with the profile of an emission line in ordinary spectroscopy. An example is shown in figure 2. The vertical line at zero velocity indicates the undisplaced frequency: the spread in frequency is entirely due to the Doppler effect. This immediately suggests one method of analysis of these data, which we may call the standard method. If we assume that the random speeds of the atoms in their 'local' surroundings are zero, so that each atom follows the circular orbit around the galactic centre with an angular velocity appropriate to its distance from the centre, then the velocity may be translated directly into distance. Consequently, a maximum at a given frequency in a line profile corresponds to a concentration of hydrogen at a particular distance. These concentrations mark the spiral arms of our Galaxy.

MAPPING THE DISTRIBUTION OF ATOMIC HYDROGEN

The same method can be worked out quantitatively, because the lifetime of the upper level of the 21-cm line is known: the emission, a spontaneous transition of the atom, occurs on the average after 11 million years. In this way it is possible to convert the line intensity at each frequency into the

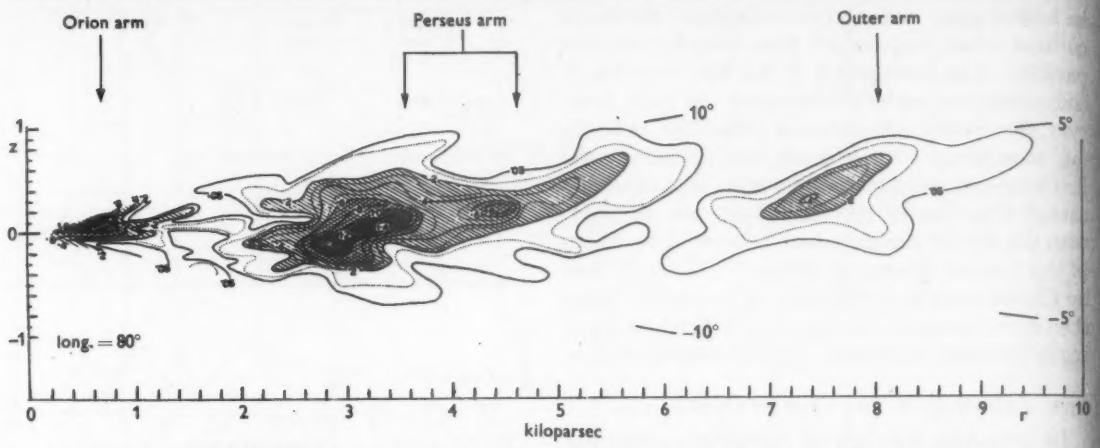


FIGURE 3 – *Cross-section perpendicular to the galactic plane. This shows isodensity contours of atomic hydrogen in a plane perpendicular to the galactic plane. The Sun (or Earth) is at the origin, r = distance from Sun along plane, z = distance from Sun perpendicular to plane. Heaviest shadings represent 2 atoms per cm³; the lowest contour represents 0·05 atom per cm³. Note here and in figure 2 that the Perseus arm is split and also that the outer arm lies above the galactic plane.*

density of hydrogen atoms at each point on the line of sight. The density varies from 2 atoms per cm³ to undetectably small values; the average for the galactic disk is about 0·7 atom per cm³.

There are, however, a number of problems that have to be solved and assumptions that have to be made before such a result can be obtained. It is necessary, for instance, to know the distance from the galactic centre to the Sun. Again, it is essential to know the rotational velocity of the stars at any given distance from the centre. Much of this information comes from optical astronomy. However, the radio measurements themselves can help in a surprising manner. When looking from our position (the Sun) in a direction inclined at an angle to the line joining us to the galactic centre we meet a point of maximum velocity at the point where the line of sight passes nearest to the centre. This maximum velocity directly gives the velocity of rotation at that point. In outward directions this method fails and a theoretical curve is used, based on an assumed distribution of mass in the Galaxy. For distances less than 3000 parsecs from the centre the method fails again, as will be seen from a later section.

The random speeds of the atoms cannot in fact be neglected. Not only do they have thermal velocities corresponding to a temperature of about 100°K, but observations show that interstellar gas clouds as a whole have random motions just as

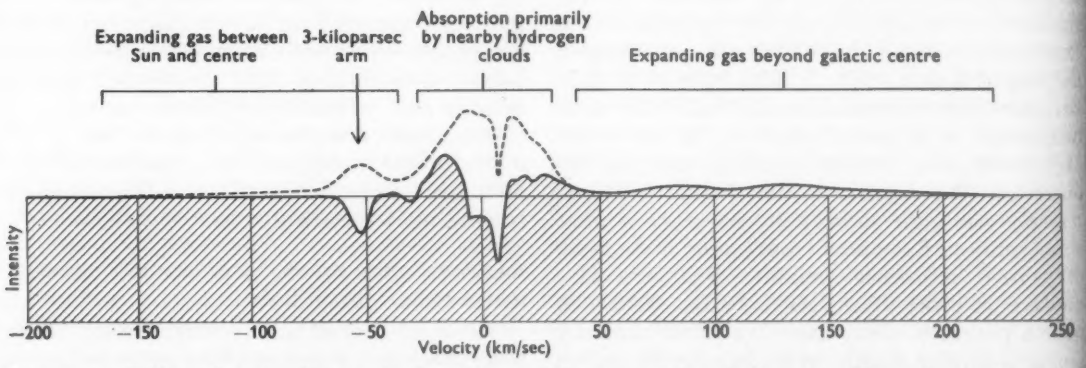
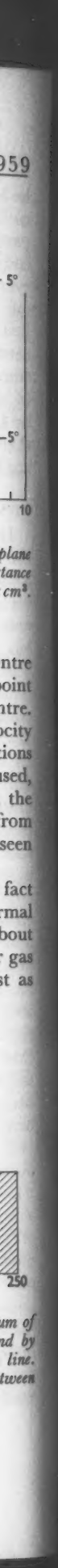


FIGURE 4 – *Evidence for expanding gas in the spectrum of the source at the galactic centre. The continuous spectrum of the source is indicated by the thin horizontal line. The hydrogen-line emission in the antenna beam, which was found by interpolation from the emission profiles at adjacent points on the sky, adds to this the intensity indicated by the broken line. The observed profile when the antenna is directed at the source is given by the solid curve. Hence the difference between the broken and solid curves shows the effect of absorption by hydrogen in front of the source.*



stars do. The consequence is that the distance scale in the standard method is blurred. This blurring is similar in its effect to the blurring in the transverse co-ordinates due to the limited resolving power of the antenna. In addition, the line profiles show clear saturation effects in the peak intensities, so that a correction for self-absorption is needed, depending on the temperature of the gas.

The data can be collected and mapped after allowances have been made for all these complications. Figure 3 shows a typical map from the complete survey at longitude 80° of the volume between −10° and +10° galactic latitude, made with the Kootwijk telescope. Hydrogen densities have been computed from line profiles of lines of sight at intervals of 2½° in latitude. The contours drawn on the basis of these data show the full distribution of atomic hydrogen in a plane perpendicular to the galactic plane. The plane is seen to cut several spiral arms and also some minor features. The major spiral arms have been given tentative names: in figure 3 the 'Orion arm' is not fully shown, because data at much higher latitude would be needed to cover it.

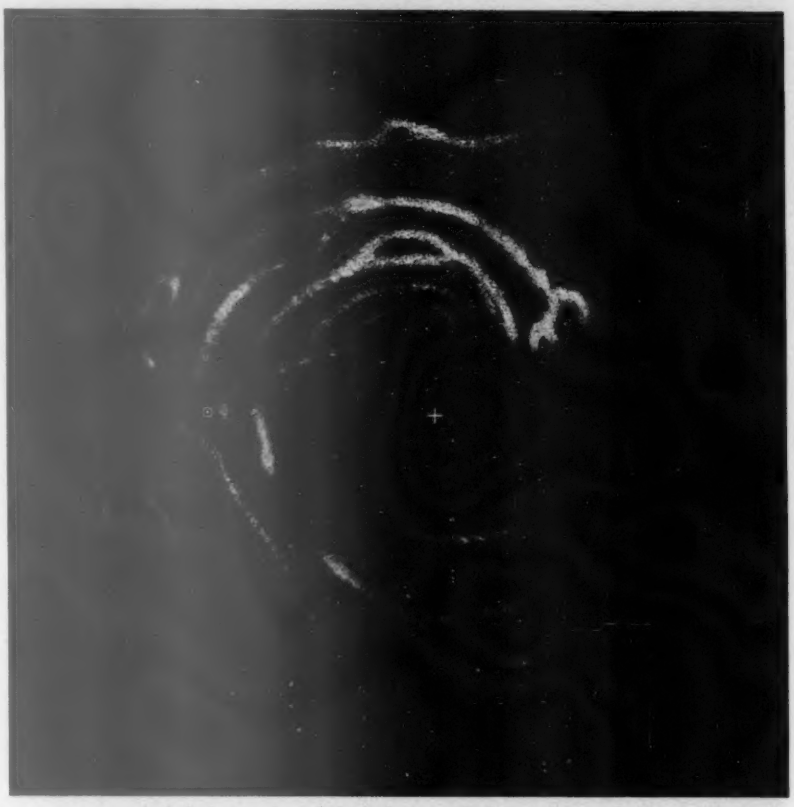


FIGURE 5 – *Artist's impression of the hydrogen spiral arms in our Galaxy. All relative concentrations of hydrogen atoms have been projected on the galactic plane.* ⊙ *= Sun,* + *= galactic centre. Sectors about the line joining the Sun and the galactic centre and opposite side have not been filled in.*

The nearer arms, or parts of them, can also be observed optically. In fact, the optical identification of the three nearest arms by Morgan and his associates in 1951 preceded the radio studies. It remains an open question whether the arms outlined by optical studies of young associations of stars, ionized gas regions, and Cepheid variables are identical with those found by observation of atomic hydrogen. The general agreement is good, but some exceptions have been noted.

About 150 maps like that shown in figure 3, obtained from observations at different longitudes, would give a complete three-dimensional picture of the hydrogen distribution in the galactic disk, subject to the limited resolving power of the 7½-metre telescope used. The approximate linear sizes that could just be resolved were 150 parsecs in the transverse co-ordinates and 600 parsecs in the line of sight. These values are far too large to see the individual interstellar clouds, the diameters of which are of the order of 10 parsecs. The blurring is just right, however, to obtain a picture of the overall galactic structure without the complication of too much detail.

Such a three-dimensional map was ready in 1955. It was incomplete, firstly because the distance determination by the standard method fails on and near the dotted line and circle shown in figure 1, secondly because approximately one quadrant of the Milky Way never rises above the horizon in Holland. Two years later Australian workers had checked a large proportion of the northern measurements by a somewhat different method and had filled in the southern gap.

To arrive at an overall picture, Westerhout and

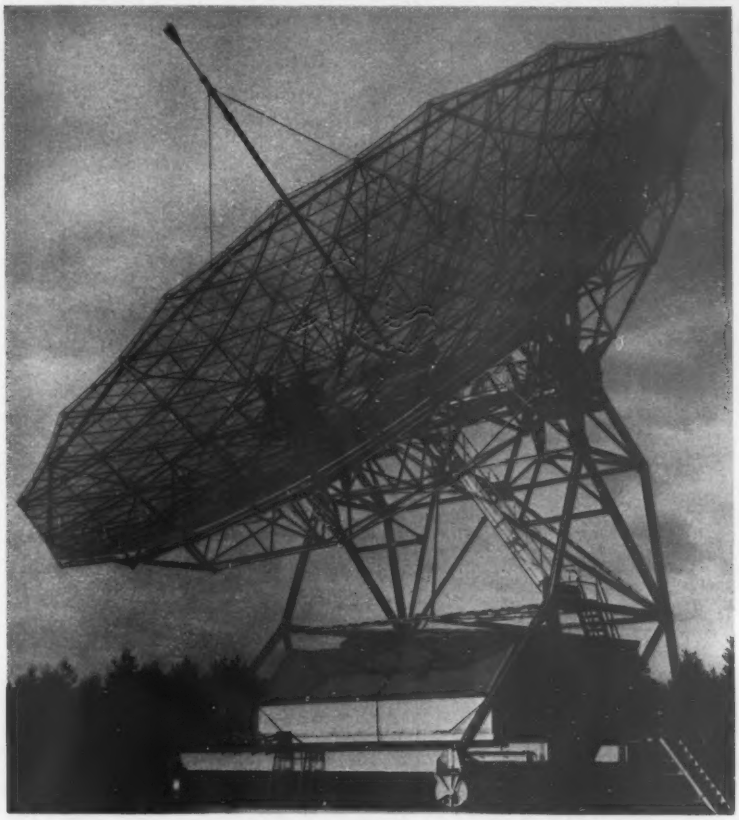


FIGURE 6 – *The 25-metre telescope at Dwingeloo.*

Kerr, with the Dutch and Australian data respectively, worked together for some months. The result can best be seen in the form of the 'artist's impression' reproduced in figure 5. This brings out both the strong and the weak features better than an isodensity contour map does. Although most of the hydrogen is confined to a narrow and surprisingly flat layer, the arms in the outer parts tend to deviate somewhat from this plane. The drawing reproduced in figure 5 accurately renders all well-established details in and near the plane. Thus it is the direct picture which a hypothetical observer in a different galaxy, fitted with eyes like giant radiotelescopes, would get of our galactic system. The details he sees are the 'spiral arms'.

It may rightly be asked, on inspecting this map, whether the term 'spiral arms' is not too fanciful. The purpose of making this drawing is, of course, to compare it with photographs of other spiral galaxies, formerly called spiral nebulae. We should, however, remember that the map is incomplete and may be distorted. There are two reasons for this. Firstly, local deviations from circular motion may suggest displacements in distance which are in fact displacements in velocity. Secondly, the sectors around the directions towards the centre and away from it have not been filled in because the method does not work there. These sectors should contain as much hydrogen as other parts of the Galaxy. Finally, the main question remains whether the spiral arms on photographs, outlined by bright stars and gaseous nebulae, may not differ from the hydrogen arms. This question cannot yet be answered, as very little is known, either from observations or from theory, about the origin and evolution of spiral arms.

In spite of these uncertainties it is possible to classify our Galaxy. Traditionally the spiral galaxies are subdivided in types Sa, Sb, and Sc. The Sa galaxies have a very large nucleus and a number of smooth spiral arms wound narrowly around it. The Sc galaxies have a small nucleus and usually two prominent patchy arms extending from it. Type Sb is intermediate. The radio map suggests strongly that our Galaxy is of the type Sb. Optical studies based on the stellar populations support this conclusion. The fact that many arms are nearly circular is not really disconcerting. The arms that do have a well-defined slope with respect to the tangential direction, especially in the outer part, all show that the sense of rotation is such that the arms are trailing.

FURTHER RESEARCH PROGRAMMES

In contrast to most of radio-astronomy, research on the 21-cm line has been relatively unexciting. The discovery was foreseen, the method of interpretation was foreseen, and even the result, a map showing spiral arms, was, in a sense, foreseen. As a result, our knowledge of galactic structure has made enormous strides in a few years, unhampered by baffling discoveries and serious misgivings about the interpretations. Nevertheless, it is a well known fact that we learn not from the predicted but from the unpredicted.

Fortunately, after achieving a few more or less foreseen results, the time comes in any investigation for the genuine surprise or even for pure groping in the dark.

This time has already come for 21-cm line astronomy. After we had found, with a moderately powerful telescope, how right we were in our assumptions, others are now working, with more powerful equipment, trying to find how wrong we were. We shall briefly mention some of the directions in which research in this field has developed during the last years.

Firstly, attempts have been made in vain to detect at least one other line. A Russian team claimed at one time to have found the deuterium line at a wavelength of 93 cm, but the latest, very accurate, measurements by the Radar Research Establishment at Malvern, England, show this line to be still below the limit of detection.

Secondly, studies on the major part of the sky, outside the 20° belt along the Milky Way, have started. A fine overall survey was made by the Carnegie Institution in Washington, and regions of special interest, such as those in the constellation Orion, were studied at the Harvard Observatory and at Dwingeloo. The hope has almost vanished that such studies would tell us something about the huge halo surrounding the Galaxy. On the contrary, it is more likely that these regions of the sky tell us about only a very local part of the galactic disk. The possibility of resolving details of interstellar gas, with a size of 1 parsec, at a typical distance of 100 parsecs, is quite exciting. Probably the convenient working model of loose interstellar clouds with sizes of the order of 10 parsecs will have to be thoroughly revised.

Thirdly, there are about five sources of continuous radio emission strong enough to provide an absorption spectrum of the 21-cm line. Several of these sources have angular sizes of 5 minutes of arc or smaller. They have given radio-astronomers at Jodrell Bank, at the Naval Research Laboratory, Washington, and later those at Dwingeloo a chance to sample the hydrogen velocities in a very small solid angle while, incidentally, giving useful estimates of the distances of these sources.

Fourthly, other galaxies have been measured. The Radio-physics Laboratory, Sydney, completed a very fine investigation of the two Magellanic clouds several years ago. About half the masses of these nearer galaxies, which are small companions to our own, prove to consist of atomic hydrogen. Our own Galaxy, by contrast, contains about 2 per cent of atomic hydrogen. The well-known Andromeda nebula, an Sb system as our own appears to be, is about twice as large as our Galaxy and has only 1 per cent hydrogen. This nebula and half a dozen others have been investigated at Dwingeloo and at Harvard. The further step, to investigating even more remote objects in the universe by means of the 21-cm line, has not yet been made with certainty, although radio-astronomy in the wider sense has led to many reliable results in this field.

EXPANSION NEAR THE GALACTIC CENTRE

Finally, our own Galaxy provided a big surprise. It has become increasingly clear in the past two years that the hydrogen gas in the central parts of the galactic disk is expanding as well as rotating. This phenomenon, discovered at Dwingeloo and still almost entirely unexplained, is the most exciting result so far obtained in the whole of 21-cm radio-astronomy. All telescope time during the three hours of the day or night that the region near the galactic centre is above the Dwingeloo horizon has been reserved for many years to come for a further study of the phenomenon. It therefore seems fitting to use the remainder of this article to describe briefly the observations that have led to this discovery.

The observations that were aimed at finding the rotation law of the inner parts of the Galaxy met a difficulty in 1954. The method consisted of trying to find the maximum velocity in each direction of the galactic plane. This worked quite well at angles (longitude differences) of 25–65° from the direction of the centre. However, at longitudes less than 25° from the centre, no clear maximum velocity was found. Instead, the line profiles showed wings of low intensity with velocities reaching high values. Quite near the centre the wings were found at both positive and negative velocities, one of which is forbidden on the assumption of rotation. The clear inference was that the gas within 3000 parsecs from the centre had a motion quite different from simple rotation: we suspected turbulence.

However, the observations of these wings with the more powerful equipment at Dwingeloo at once revealed much detail, a result not in accordance with a general state of turbulence. Rather, a maximum occurring at a certain frequency at one longitude was usually found with a slightly displaced frequency at an adjacent longitude. This is just like the spiral arms found in the outer parts

of the galactic system. But the 'forbidden' velocities remain, so that these arms cannot be located in space by the standard method.

The most prominent arm in this region can be followed over a 28° interval of longitude. By interpolation from adjacent longitudes, its velocity component in the line of sight, observed in the exact direction of the galactic centre, should be −53 km/sec. In this direction there is a strong source of continuous radio emission, which most probably is at the actual centre of the Galaxy. The continuous spectrum of this source makes it impossible to observe the 21-cm emission line in the normal manner. Instead we see a complicated spectrum, (figure 4) with absorption components (clouds of hydrogen atoms in the small solid angle subtended by the source), together with emission components (clouds of hydrogen atoms in the antenna beam but not covering the source). Early in 1957 it was found that a strong absorption line occurs exactly at −53 km/sec. This must be interpreted as representing the same spiral arm cutting between us and the galactic centre and having at that point a velocity component of 53 km/sec towards us. This is a velocity away from the centre—that is, an expansion. The transverse (rotational) velocity cannot be established exactly but is estimated from the observations at other longitudes to be 190 km/sec. This arm is probably at the fringe of the exceptional region and is called the '3-kiloparsec arm'.

It is significant that a few other, less prominent, arms having positive velocities also extend to the centre direction but are not found in absorption spectra. Hence they must be beyond the galactic centre, and their motion away from us is again an expansion away from the centre. When this had been found, it became really urgent to investigate systematically and with great accuracy the presence of possible absorption in the spectrum of the centre source at all Doppler displacements from −300 km/sec to +300 km/sec. The result, briefly explained in figure 4, is striking. No absorption at all is seen at the positive velocities. However, all negative velocities show a more or less prominent absorption effect. This shows that the phenomenon of expansion is not limited to a few spiral arms, but is common to all atomic hydrogen in this central part of the galactic system.

The explanation of this expansion seems almost impossible at the moment. One of the most puzzling facts is that the atomic hydrogen here, as elsewhere, is confined to a thin layer along the galactic plane. It is even a little thinner: about 100 parsecs. Any force giving rise to the expansion has to be highly directive along this plane. Another problem to be solved is where the hydrogen comes from. It seems difficult to postulate a source at the centre which is gradually becoming exhausted during the life of our Galaxy. More probably the material is sucked in from the galactic halo, where it has been present as a fully ionized, very tenuous gas. The general feeling is that somehow magnetic forces will prove to be responsible for all this, but more observation and more thought will be required before the situation can be clearly understood.

ACKNOWLEDGMENTS

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The use of pituitary hormones in fish culture

JAMES W. ATZ and GRACE E. PICKFORD

Fish farming could be much more important than it is, particularly in areas of overpopulation and malnutrition. The problem has always been that many food-fish will not spawn in captivity. One possible solution lies in the use of pituitary extracts, which stimulate spawning. These have been found of value both for intensive fish cultivation and for solving the problems caused by damming the rivers in the Soviet Union in which the sturgeon breed. The experiments, results, and some applications are described in this article.

Fish have been kept in captivity since ancient times; as far back as 2000 B.C. the Sumerians maintained food-fish in ponds [1]. Fish domestication, however, has lagged behind that of mammals, birds, and insects. By 1000 A.D. only two species, the carp (*Cyprinus carpio*) and the goldfish (*Carassius auratus*), had been domesticated, both in China [2, 3]. The methods of culturing eggs and fry of freshwater food- and game-fish, first developed in Europe during the eighteenth and early nineteenth centuries, made it feasible to rear trout, pike, and similar species, but unwarranted enthusiasm regarding the effectiveness of stocking natural waters with young fish and the lack of economic incentive to raise these species to maturity in captivity impeded their domestication. Even today only a few species, notably the rainbow trout (*Salmo gairdneri*), can properly be said to be domesticated. In the Far East, the Siamese fighting fish (*Betta splendens*) has been selectively bred for combativeness during the past century [4], and more recently a number of other small tropical freshwater species have qualified as domestic animals by virtue of their continued propagation and selection in homes and hatcheries.

In contrast to these species, there are food-fish that have regularly been raised in ponds for many decades—some for centuries—that have not become domesticated, simply because they have refused to reproduce in captivity. Included among these are some of the most important edible species—the striped mullet (*Mugil cephalus*), the milkfish (*Chanos chanos*), and several carp-like species from India, China, and south-east Asia (such as *Ctenopharyngodon idellus*, *Aristichthys nobilis*, and *Hypophthalmichthys molitrix*). Since the fish farmer cannot breed these fishes, he is at the mercy of the available supply of fry spawned in the wild. Each year he must catch or buy fresh stock, and he is helpless if conditions are unpropitious for spawning in nature. Accurate figures are not available, but estimates of a decade ago indicate that more than a million acres of ponds were then employed in raising such fish, total production being of the order of half a million tons a year [5].

In a world where the human population is increasing at a rate of 25 million each year, and where half the people are already undernourished, no opportunity to improve the productivity of any important source of animal protein food can be neglected, especially if such food can be produced in the very regions where the greatest shortages of this vital component of man's diet occur.

One approach is suggested by the experiments of B. A. Houssay of Argentina, who in 1930 injected some small viviparous fish with pituitary glands recently removed from another species of fish, and brought about premature birth of the young [6]. Present-day concepts of the role of the pituitary gland (hypophysis) in the reproduction of vertebrates may be considered to have commenced three years before, when S. Aschheim and B. Zondek found that pituitary implants accelerated the sexual development and cycle of female mice, and P. E. Smith for the first time unequivocally demonstrated the effects of hypophysectomy and subsequent replacement therapy on the gonads of the laboratory rat [7]. Houssay, who has so often approached physiological problems from the comparative point of view, was not long in applying similar techniques to amphibians and fishes. His work soon came to the attention of R. von Ihering, Director of the *Comissão Técnica de Piscicultura do Nordeste*, at Ceará, Brazil. For years the chief problem in Brazilian fish culture had been to get native freshwater food-fish to spawn in captivity. Even when caught in a nearly ripe condition these species rarely, if ever, completed the maturation

of their sex products, which degenerated instead. In nature, spawning precipitously follows the first storms of the rainy season, but the effective environmental stimuli could not be determined and thus duplicated in captivity. By 1934, after two to three years of experimentation, von Ihering and his collaborators had developed a successful technique for inducing pond-fish to spawn by injecting them with the pituitaries of other fish.

The pituitary gland is basically similar in all classes of vertebrates. It is a small body, located at the base of the brain (figure 1). Although small, it is a major controlling factor or 'master gland' in the animal's hormonal regulatory system. In a fish about one foot long the pituitary is about as large as the head of a match, and weighs from one to ten milligrams. In fish, as in other vertebrates, the pituitary is vitally concerned with the regulation of growth and of pigmentation, the adrenal cortex, the thyroid gland, and a number of less clearly understood functions, as well as with reproduction. Although the form and arrangement of the parts of the fish pituitary differ strikingly from those found in the higher vertebrates, the same essential elements are present, and, as far as known, the same types of cells are responsible for the production of the eight or more different hormones released by the gland in the course of its normal activities. Cyclical changes in the pituitary gland of fishes, correlated with the reproductive cycle, are striking (figure 2). They clearly show the increase and decrease in the cyanophil cells concerned with the production of gonad-stimulating hormones (gonadotropins), as well as showing the depletion of neurosecretory material associated with the release of these hormones.

As far as is known, all the hormones of the hypophysis are protein in character. Each kind of hormone appears to be basically of the same chemical structure, at least in the mammalian species that have been studied. It is clear, however, that there are important differences in the amino-acid sequences and physico-chemical properties of purified preparations derived from different vertebrate sources [8].

These differences may be the basis of the phenomenon of 'species specificity' which expresses itself as the tendency of one species to respond poorly, or not at all, to pituitary hormones from another. Nevertheless, the mammalian pituitary is still capable, in some instances, of stimulating the piscine gonad; the converse is also true [9–11, 27].

This situation is of fundamental importance to the fish culturist. A few species of fish will yield ripe eggs or sperm when treated with mammalian pituitary extracts, but most will not. The gonadotropic hormones extracted from pregnant mare serum or human pregnancy urine rarely work any better. The fish culturist is therefore seldom able to use commercially available extracts. Instead, he must employ preparations of fish pituitaries that he has to make himself.

Numerous endocrinological experiments on mammals and birds are most easily explained by postulating that the pituitary produces two gonadotropins. Chemical separation of the follicle-stimulating hormone (FSH) and luteinizing hormone (LH) has been reported in numerous investigations. Nevertheless, the possibility that the naturally occurring gonadotropin is a single, multipurpose hormone which is broken down by chemical fractionation cannot be excluded, and the duality of the gonadotropins has been repeatedly questioned [12].

The problem is equally complex in fishes. There is no evidence that fish respond to mammalian FSH [13], whereas the piscine gonad is readily stimulated by LH. Yet, by mammalian assays, both FSH and LH activities appear to be present in the fish pituitary [10, 14]. Moreover, studies of the maturation of fish gonads and their regulation by environmental conditions suggest that different processes may be concerned in the earlier and later stages, and that ovulation is an independent event. In some species [15] only the second process (yolk production) is light-dependent, and in most species the third (ovulation) does not occur unless suitable environmental conditions prevail [16]. Different processes suggest the release of different pituitary hormones. Moreover, the synergic action of growth hormone, thyrotropic hormone, and sex steroids is strongly indicated and may account for the better results obtained with crude than with purified gonadotropic preparations.

The regulation of the release of pituitary gonadotropins, initiated by environmental stimuli, is mediated through hypothalamic centres at the base of the brain. In warm-blooded vertebrates there is a hypothalamo-hypophysial portal system, a local vascular connection, that is believed to carry neurosecretory products from the hypothalamus to the hypophysis and thus to participate in the production and release of pituitary hormones. A similar arrangement exists in sharks and rays, but the bony fishes lack this vascular connection [17], and neurosecretory products are apparently

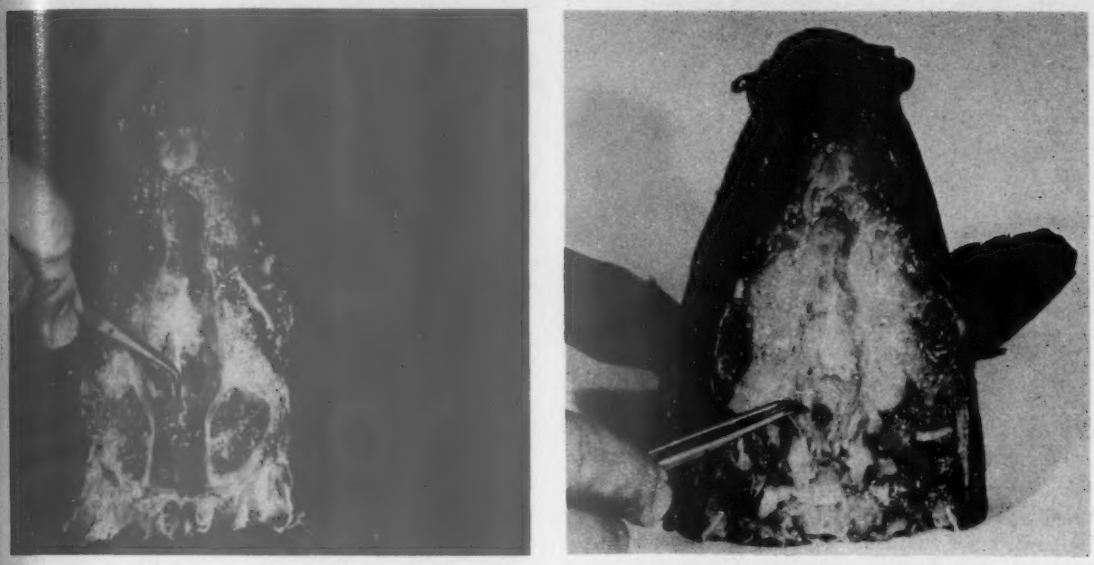

FIGURE 1 – *Dissection of fish to obtain pituitary gland. (Left) First stage: head of carp with brain case removed to expose brain. (Right) Second stage: brain removed to expose pituitary. (By courtesy of Robert C. Ball.)*

transmitted from the hypothalamus by way of nerve fibres which, in this group, ramify throughout the hypophysis [18]. Numerous studies have shown that specific hypothalamic centres in the teleostean brain undergo seasonal changes in secretory activity correlated with the reproductive cycle [19, 20].

The theoretical considerations outlined above have had an important bearing on the practical procedures that we are about to discuss. Brazilian fish culturists soon improved their simple yet successful technique. They learned that donor fish must be in the right stage of the reproductive cycle, because, if they are immature or have recently spawned, their pituitaries are ineffective owing to the low concentration of gonadotropin. Glands from a variety of donor species could be preserved for future use by dehydrating them in acetone or absolute alcohol. Females generally required higher doses than males. Small multiple injections gave better results than did single large ones. In practice, from four to eight intramuscular injections are given, usually at six-hour intervals, until the fish show by their behaviour that they are ready to spawn. A partition separating males from females in the aquarium is then removed and spawning is allowed to take place. The total amount of pituitary extract administered may be equivalent to as little as one-half or to as much as five glands, depending on the responsiveness of the recipient.

By far the most extensive use of pituitary treatment in pisciculture has been made in the Soviet Union. The Russians first attempted to induce captive sturgeons to ripen or spawn in 1932 by means of mammalian hormones, but it was not until 1937 that N. L. Gerbil'skii was able to obtain ripe eggs and sperm from a significant number of sturgeon (*Acipenser stellatus*) that had been intracranially injected with one or two fresh pituitaries of the same species. Since then pituitary treatment has played an ever-increasing role in the conservation of sturgeons in Russia. More and more dams, locks and hydro-electric plants are being built along the Russian rivers, and these present insurmountable barriers to sturgeon, which must travel upstream to spawn. Stations for sturgeon culture at one time had to be located near the spawning grounds; with the advent of artificially induced ripening these could be moved near the mouths of the rivers, since the final stages of maturation could now be hormonally effected. In 1950, the latest year for which figures are available, nearly nine hundred females belonging to the two most commercially important Russian species of sturgeon were treated. Today the Russians obtain all sturgeon eggs for culturing from pituitary-treated fish [21].

For this purpose, sturgeon pituitary glands are collected on a large scale, utilizing fish taken in the extensive commercial fisheries. A team of four men can remove and preserve about five hundred

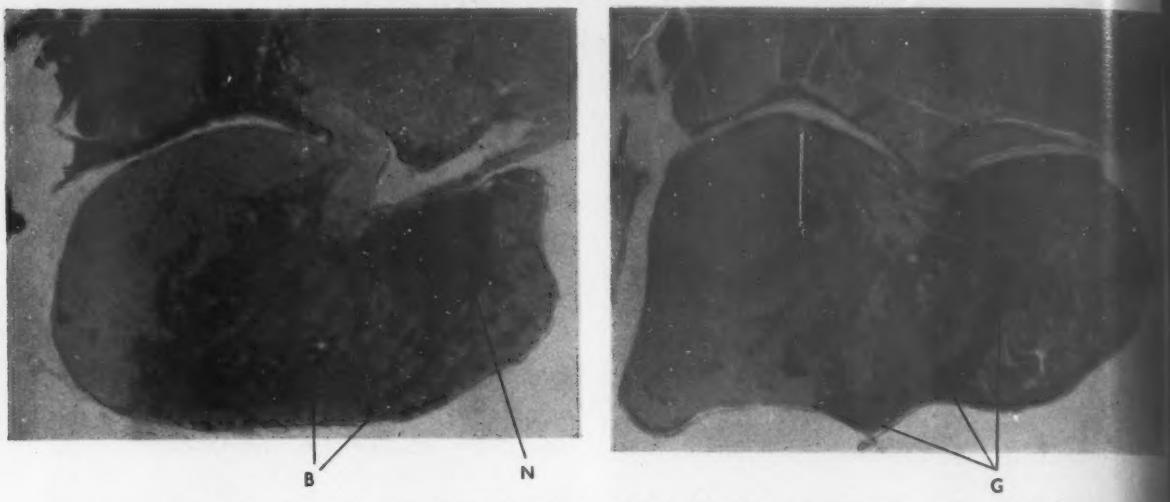

FIGURE 2 – *Seasonal changes in the hypophysis of the killifish,* Fundulus heteroclitus, *correlated with sexual maturation and regression. Sagittal sections of the pituitary gland of male fish, fixed in Bouin's fluid, sectioned at* 4 μ, *and stained by the aldehyde fuchsin (AF) method. (Left) In December (winter regression). The basophils (B) of the meso-adenohypophysis* (Übergangsteil) *are small and show comparatively few AF-positive granules in the cytoplasm. The neurohypophysis contains abundant accumulations of neurosecretory material (N). (Magnification* × 380.) *(Right) In May (early in breeding season). About half of the basophils of the meso-adenohypophysis are large and filled with deep purple AF-positive granules (G). The most peripheral basophils of this zone, which are sparsely granulated at this time, would be densely packed with AF-positive material in June. Neurosecretory material is sparse in the neurohypophysis. (Magnification* × 220.) *(By courtesy of Hilda Weyl Sokol.)*

glands a day.[1] After dehydration in acetone, the glands are stored dry in tightly sealed bottles. A single intramuscular injection of aqueous extracts from two to four glands is given to each fish, which is maintained along with others like it in a pond furnished with running water. In order to make certain that the gonads of females are sufficiently mature before injection, they may be inspected through an incision in the body wall. Injected males and females are kept together and examined periodically for the correct stage of ripeness, at which time the females are opened and their eggs artificially fertilized with milt taken from males. Gerbil'skii's method of injecting the pituitary material inside the skull is no longer employed, probably because of the high degree of skill required to avoid serious injury to the fish.

Not all the sturgeon that enter a river are mature enough to be able to respond to pituitary treatment; in fact, a species may be divided into as many as four different seasonal 'races', each race being characterized by a different time of entry into the particular river in question. Some races proceed immediately to the spawning grounds; others require several weeks before they ripen; still others remain more than six months in fresh water, hibernating over winter, before they spawn. The necessity of adapting pituitary treatment to this situation has stimulated the Russians to study the phenomenon of biological races among fish that migrate into fresh water to breed, and to attempt to correlate their existence with the different ecological conditions found in various rivers [22].

Experiments on the pituitary treatment of fishes have also been performed in at least eight European countries and in Japan and in Argentina, apparently without practical application to pisciculture. The reasons for this are not far to seek. Fish culture is relatively unimportant in most temperate countries, and those species that are raised in quantity, such as carp and rainbow trout, respond well to techniques that were perfected long before the functions of the pituitary were understood. In the United States, however, the injection of fishes with pituitary hormones is now regularly employed to produce goldfish for the pet trade, and also to obtain goldfish-carp hybrids. These latter are useful as bait, since they

[1] Much faster work can undoubtedly be done with the use of a meat-cutter's band-saw, at least in the case of such species as carp, cod, pollack, and hake. We have found that a team of two workers, a head-cutter and a gland-picker, can process as many as 500 fish heads in an hour by this means.

are sterile and cannot overrun streams or lakes and spoil them for native food- and game-fish, as the parent species have done in the past. The method is now being adapted for the mass production of native minnows for bait, the culture of channel catfish (*Ictalurus punctatus*), and the conservation of Pacific salmon (*Oncorhynchus* spp) that have been prevented from reaching their upstream spawning areas by man-made obstacles. Unfortunately, methods that were successful with trout (*Salmo* spp) have so far proved almost total failures with salmon (*Oncorhynchus* spp) [23].

Promising developments have recently occurred in India. The principal problem in Indian fish culture has been obtaining seed fish regularly. When the monsoons failed or other unfavourable conditions prevailed during the spawning season, serious shortages of food-fish resulted. H. Chaudhuri of the Central Fisheries station at Cuttack, Orissa, has now been able to induce spawning in six species of carps with as little as a single intramuscular injection derived from one twenty-fifth of an alcohol-preserved gland taken from one of a number of species of donor carp [24]. The practicability of the pituitary method for Indian pisciculture was established beyond doubt in 1958, when fishery officers were successful with it in five other states [25]. In addition, three species of freshwater catfish from India have been treated successfully, two of them with mammalian hormones [26].

In most of the investigations cited in preceding paragraphs the problem has been relatively simple, since hypophysis injections could be administered to fish already close to natural spawning. However, the Russians have found it necessary to keep sturgeon of certain biological races in ponds for weeks or months until they reached the right stage of maturation, after which a single hypophysis injection is effective. The induction of growth and maturation of the gonads in fish that fail to approach sexual maturity under conditions of pond culture presents an acute problem. Most of the species of carp employed, for example, in the Chinese method of mixed carp culture, rarely if ever mature. The same is true of the milkfish, the striped mullet, and the Siamese catfishes (*Pangasius* spp). Although complete maturation of the regressed testes of hypophysectomized fish has been achieved as a laboratory experiment, no similar results have been reported for the reproductive organs of the females. Even if such results could be produced by treatment with suitable mixtures of hormones over long periods of time, it is doubtful whether this problem could be solved on a practical basis by hormonal treatment alone. Attention must rather be given to the improvement of environmental conditions favouring natural maturation of the gonads in breeder fish.

It is hoped that the foregoing brief account may serve as a stimulus to pisciculture, especially in those areas of acute protein shortage in which difficulties of domestication have hampered pond culture.

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The mammalian egg

C. R. AUSTIN and E. C. AMOROSO

The egg is a most unusual cell, not only on account of its great size but also because it passes through a series of changes, here described, of so radical a nature that it is commonly referred to as though it were a succession of separate cells. The illustrations to this article have been obtained by a combination of classical and newly devised histological techniques that have all played a part in advancing our knowledge of the beginnings of embryonic development.

'Led by curiosity . . . I opened one of the follicles and took up the minute object on the point of my knife, finding that I could see it very distinctly and that it was surrounded by mucus. When I placed it under the microscope I was utterly astonished, for I saw an ovule just as I had already seen them in the tubes, and so clearly that a blind man could hardly deny it.' In these words von Baer announced his discovery to the world of 1827 and brought to an end a search that had gone on for over 2000 years [14].

In the fourth century B.C. Aristotle concluded from his patient and thoughtful investigations that many animals, including mammals, originated in the admixture within the uterus of menstrual blood and the male semen. From these materials, he maintained, a coagulum was produced that gradually became organized into the tissues and organs of the foetus. He did not associate the ovaries with the reproductive process and believed the semen was produced, not in the testes, but in the seminal ducts. The ovaries were first identified as being implicated in reproduction about 500 years later, when Galen taught that the female equivalent to the male semen was a substance of similar nature that was separated by the ovaries from the blood stream and passed down the Fallopian tubes to the uterus.

These beliefs were held for over fourteen hundred years. Then, in 1672, de Graaf published a book in which the mammalian ovary was clearly and accurately described, and evidence was brought forward showing its function to be analogous to that of the hen's ovary. De Graaf had found small round objects in the uterus of the rabbit that he termed 'eggs' (they were in fact blastocysts, like those shown in figure 18) and similar though smaller ones in the Fallopian tubes. He was unable to find anything but fluid within the follicles, but maintained that the contents of the follicle were released and, passing through the Fallopian tube, became constituted into the 'eggs' from which the embryo would eventually hatch within the uterus.

Despite the attempts of numerous investigators, de Graaf's observations on tubal embryos were not confirmed for many years and, as no one could find recognizable structures in the follicle either, much of his theory fell into disrepute. Just over a century later, in 1797, Cruickshank reported that he too had observed tubal eggs in the rabbit on the third day after coitus, and uterine embryos at later stages (figure 19). But, like de Graaf, Cruickshank was quite unable to trace the history of these objects back through the first few days. A further careful investigation, by Prévost and Dumas in 1824, was equally fruitless, though these authors must have come very close to success, for they mentioned finding small bodies about 1 mm in diameter in some follicles, and these could well have been eggs with their investments of cumulus cells. It was thus left to von Baer to recognize the egg in the ovary (figure 20) and finally to identify the source and form of the female gamete.

Subsequent developments came comparatively quickly, and the modern concept of the nature and function of the mammalian egg was fully established within the next fifty years. The nucleus of the ovarian egg, the germinal vesicle, was described by Coste in 1834. Schwann suggested that the egg is a true cell, and Gegenbauer showed this to be so. Many detailed observations were published by Barry (figure 21), and especially by Bischoff (figure 22), on the eggs of rabbits, guinea-pigs, dogs, and deer. By the middle of the century it was known that the egg of the placental mammal consists of a cytoplasmic mass or vitellus surrounded at a short distance by a thick transparent membrane, the zona pellucida. The first real clues to the cytological changes at fertilization were provided through the perspicacity of Van

Beneden and Hertwig, who showed, in 1875 and 1876 respectively, that a nucleus of new formation arose from the penetrating spermatozoon; they maintained that it was the union of this nucleus and the egg nucleus that constituted the essential act of fertilization. Notable studies on living rat eggs were made by Tafani, but it was the extensive and painstaking histological researches of Sobotta, towards the end of the nineteenth century, that were chiefly responsible for the rapid advances in detailed knowledge of maturation, fertilization, and early cleavage (figure 23).

The egg originates in the genital ridges of the embryo, where early germ-cells undergo several mitotic divisions and give rise to primary oocytes. These oocytes do not divide, but grow enormously in size and accumulate yolk material in their cytoplasm; they become surrounded first by a single layer of follicle cells and later by several layers. This system is the ovarian follicle. Progressive enlargement continues and the layers of enveloping follicle cells increase in number. Within the follicle there forms a space, the antrum, containing follicular fluid. A few hours before ovulation, the oocyte (figure 1) enters upon a process of maturation by extruding the first polar body, becoming thus a secondary oocyte (figures 2, 7, and 28). Separation of the second polar body (figures 3, 27, and 36), which marks the fulfilment of maturation, occurs in most mammals only after ovulation and entry of the spermatozoon.

After ovulation, the secondary oocyte passes to the Fallopian tube, where penetration by the spermatozoon initiates fertilization. Fertilization ends with the union of male and female chromosome complements (figure 8), and the egg divides into a 2-cell embryo (figures 5 and 9). Cleavage proceeds with a succession of mitotic divisions whereby the embryo comes to be composed of a large number of small cells (figures 10–14 and 39). At first these cells gather together as a solid structure known as a morula, but later a fluid-filled cavity develops, and this characterizes the blastocyst (figures 15–17 and 42). At one point on its inner surface the blastocyst bears a group of cells, the 'inner cell mass', from which the foetus itself will develop, while the wall of the blastocyst, the trophoblast, is destined to form the foetal membranes.

The sizes of mammalian eggs, which are not proportional to the sizes of the adult mammals, differ so very much that they cannot all be conveniently measured in the same units. The early germ cells and the newly formed primary oocytes are a little bigger than the other cells of the genital ridge, but, at various times after the birth of the animal, primary oocytes undergo their immense enlargement, in which the volume increases 80- to 90-fold. To varying degrees this is attributable to accumulation of non-living yolk materials. When they have reached their full size, the eggs of placental mammals measure 60–180 μ in diameter (vitellus alone); the eggs of rodents occupy the lower part of the range (figure 24). Very occasionally 'giant' eggs are found, which are 30–40 per cent larger in diameter than normal; these are known in the rabbit, rat, and mouse [5] and the cotton-rat (figure 38). The egg of the Australian native cat *Dasyurus*, is of notably larger dimensions, namely 240 μ in diameter, but much the largest mammalian eggs are those of the oviparous monotremes, the spiny anteater *Tachyglossus*, and the duck-billed platypus *Ornithorhynchus*, in which the vitellus at ovulation measures 3·5–4 mm in diameter. Sea-urchin (*Arbacia*) eggs are much the same size as rodent eggs, the vitellus having a mean diameter of 74 μ. By comparison, fish eggs vary between 400 μ and 150 mm, and frog eggs between 700 μ and 10 mm [8]. On the other hand, the oval egg of the parasitic nematode *Ascaris* has diameters of about 60 and 45 μ, and that of the trematode *Clonorchis* only 28 and 14 μ.

The eggs of placental mammals, with volumes between 100 000 and 3 000 000 μ^3, and that of *Dasyurus* with a volume of about 7 000 000 μ^3, are very big compared with most tissue cells, of which the volumes lie between 200 and 15 000 μ^3. A motor neurone in a large mammal, however, would have a volume of the order of 10 000 000 μ^3, mainly on account of its remarkably long axon. The smallest mammalian cells are probably the red blood cells and spermatozoa, of which the volumes are about 100 μ^3 and 30 μ^3 respectively.

THE NUCLEAR STRUCTURE OF THE MAMMALIAN EGG

The nucleus of the early germ-cell as seen in histological preparations contains a fine reticulum with scattered chromatin granules and one or two nucleoli. The oocyte nucleus is similar when first formed, but soon undergoes a series of changes that are part of the prophase of the first meiotic division. Meiosis does not occur, however; instead, the nucleus passes into a prolonged resting state, which persists until maturation begins at puberty or later. When the great enlargement of the oocyte occurs the nucleus grows also, to reach

a relatively enormous size (figures 1 and 43)—about 18 000 μ^3 in the rat egg—which is larger than the whole volume of most tissue cells. A distinctive feature of the oocyte nucleus at this stage is the large nucleolus, about which exist high concentrations of deoxyribonucleic acid (DNA) (figure 1). Presumably this can be ascribed to aggregation of the partially condensed heterochromatic regions of chromosomes. The oocyte nucleolus contains little or no ribonucleic acid (RNA), which is a component of most tissue-cell nucleoli.

Maturation involves the reduction of the chromosome number to half, which is brought about in the course of two meiotic divisions. In the later stage of prophase, the chromosomes, already arranged as homologous pairs, can each be seen to have split into two units (chromatids), but each chromosome still has only one centromere. Crossing over of parts of homologous chromosomes now occurs, permitting rearrangement of genetic material. The modified members of the chromosome pairs are parted and move to opposite poles of the spindle, one group passing into the first polar body. The chromosomes then at once regroup on the second meiotic spindle. As a general rule, the second meiotic division is arrested at metaphase and proceeds only after ovulation and penetration by the spermatozoon. When it continues, the centromeres divide and the constituent chromatids of each chromosome separate, half of them passing into the second polar body. The chromatids thus become the chromosomes of the next generation.

Following the entry of the spermatozoon, both spermatozoon head and the group of egg chromosomes are transformed into nuclei, known as the male and female pronuclei respectively. There is an apparent hydration of the head and a clumping of the egg chromosomes (figure 3; the polar-body chromosomes lying at a lower focal plane are also visible). Within each mass, nucleoli make their appearance, and soon an encircling nuclear membrane becomes evident. A detailed account of fertilization appears in a recent review [7].

Pronuclei contain one or often more nucleoli suspended in a fluid medium, the nucleoplasm (figures 4, 23, 31, 32, and 33). The number may often be greater than the haploid chromosome number of the animal: in male pronuclei in rat eggs, for example, as many as 35 nucleoli have been recorded, although the haploid number in the rat is only 21. This may mean that nucleolar materials can accumulate to visible proportions in sites other than the nucleolus organizer present on certain chromosomes, or that there is more than one nucleolus organizer on any one chromosome, or that nucleoli can be detached from their sites of formation, leaving the positions free for the development of further nucleoli.

Larger eggs tend to have relatively smaller pronuclei, probably because they carry more yolk. Thus the ratio of pronuclear volume to vitelline volume at the peak of pronuclear growth is 1 : 25 in the rat egg and 1 : 88 in the rabbit egg. As in other cells, there may be a direct relationship between the nuclear size and the mass of active protoplasm. The size of nucleoli relative to that of the pronuclei also differs in different eggs. In the living rat egg the total volume of nucleoli is approximately one-tenth that of the pronuclei; in the rabbit egg, on the other hand, it is only one-hundredth. Observations on the living eggs of other rodents and on the fixed eggs of various mammals show that small eggs have relatively large nucleoli and large eggs often have small nucleoli (compare figures 31, 32, and 33). Large nucleolar size is generally held to be associated with a high rate of protein synthesis. Perhaps this means that small eggs, with their more limited stores of nutrient materials, must undertake more intense synthetic activity.

Studies on centrifuged eggs show that the nucleoli are of higher specific gravity than the other components of the pronucleus. Pronuclear nucleoli consist chiefly of basic protein and phospholipid and possess little or no nucleic acid. They contain acid phosphatase, and also inclusions of mucopolysaccharide which some authorities believe are passed into the cytoplasm as specific products of nuclear synthesis [15].

The nucleoplasm in the pronuclei of living eggs is structureless when viewed with the phase-contrast microscope, though it is presumably occupied by the chromosomes in an extended form. Moderate concentrations of DNA are readily demonstrable in early pronuclei, uniformly distributed through the nucleoplasm (figure 4). The amount of DNA in each pronucleus is half that present in tissue-cell nuclei, for DNA is the characteristic component of chromosomes and the pronuclei contain half the somatic number of chromosomes (like the egg, the spermatozoon loses half its chromosome complement during maturation). As the pronuclei grow, the concentration of DNA falls, for the total amount remains constant. Later in pronuclear life, however, an extra complement of DNA accumulates

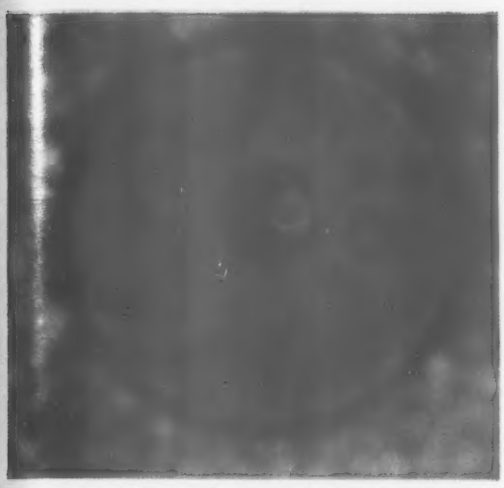

FIGURE 1 – *Primary oocyte, surrounded by cells of the cumulus oophorus.*

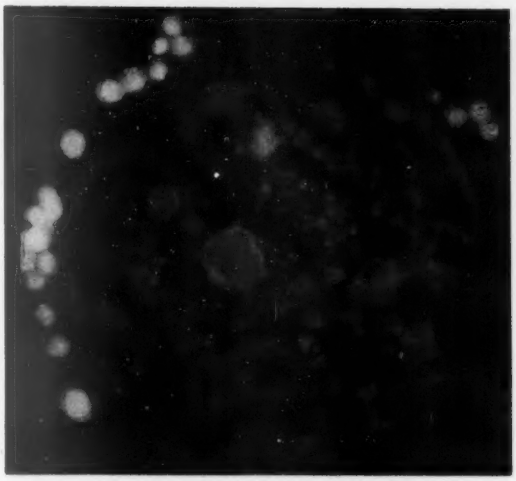

FIGURE 2 – *Secondary oocyte (unfertilized tubal egg) with the green fluorescent chromosomes on the second meiotic spindle.*

FIGURE 3 – *Early fertilization; the spermatozoon head and the telophase chromosome groups fluoresce green.*

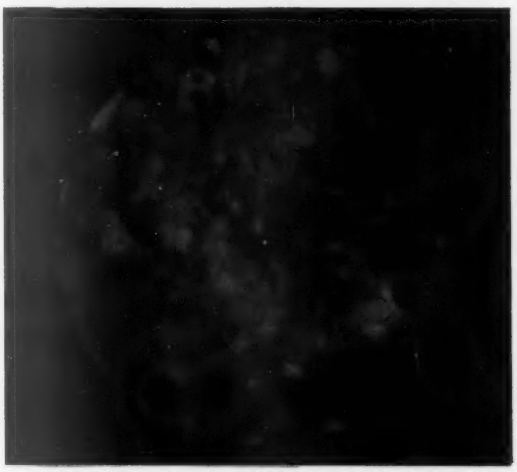

FIGURE 4 – *Pronucleate egg. The female pronucleus is above and the male below and to the right.*

FIGURE 5 – *Two-cell egg. The nuclei, and the chromosome group in the polar body, fluoresce green.*

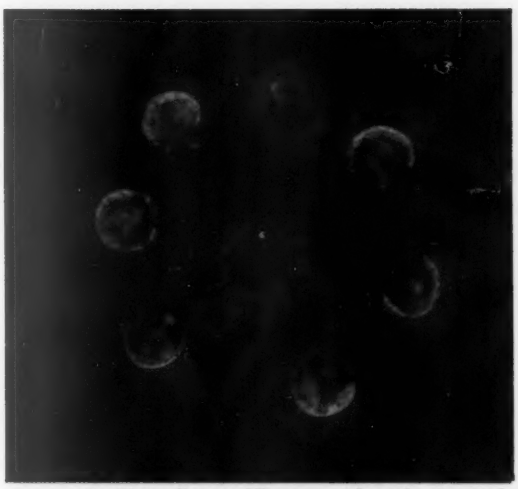

FIGURE 6 – *Eight-cell egg. The aggregated cytoplasmic granules fluoresce red.*

FIGURES 1–6 – *Stages in the development of living rat eggs, showing fluorescence induced by treatment with acridine orange (ca. × 500; eggs somewhat flattened by coverslip).*

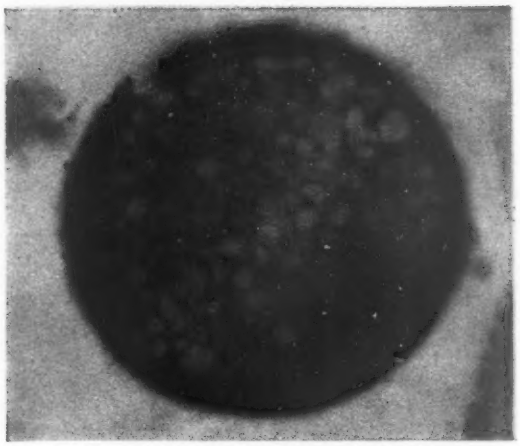

FIGURE 7 – *Secondary oocyte with second meiotic chromosomes.*

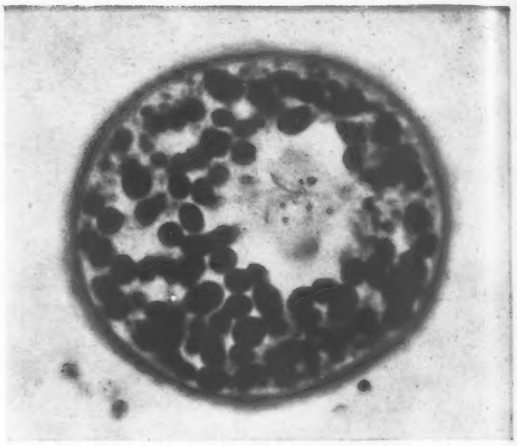

FIGURE 8 – *Syngamy. Fat droplets stained.*

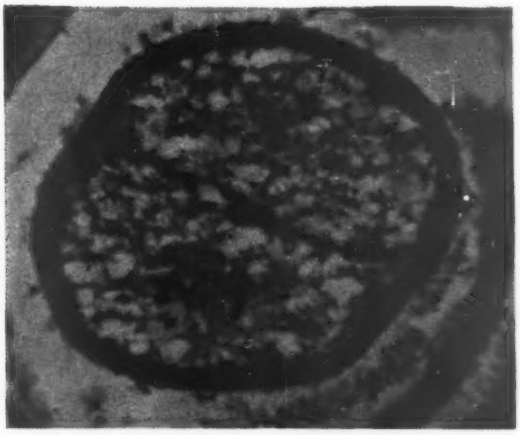

FIGURE 9 – *Two-cell egg with a second-cleavage spindle.*

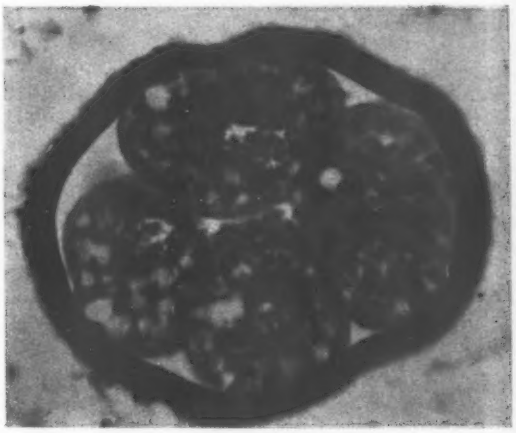

FIGURE 10 – *Four-cell egg.*

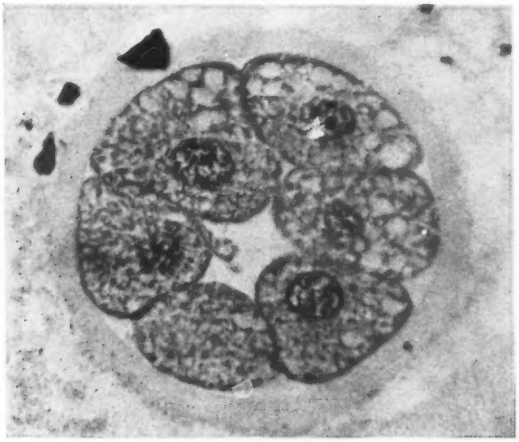

FIGURE 11 – *Eight-cell egg; only six of the blastomeres are visible in this section.*

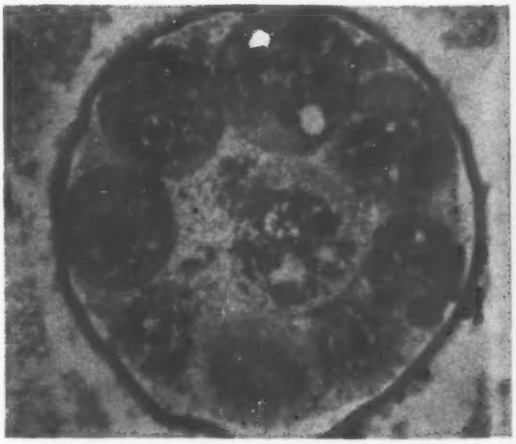

FIGURE 12 – *Morula. Fat droplets stained.*

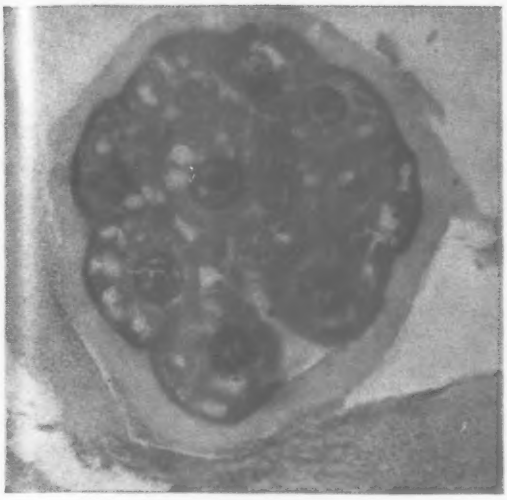

FIGURE 13 – *Morula.*

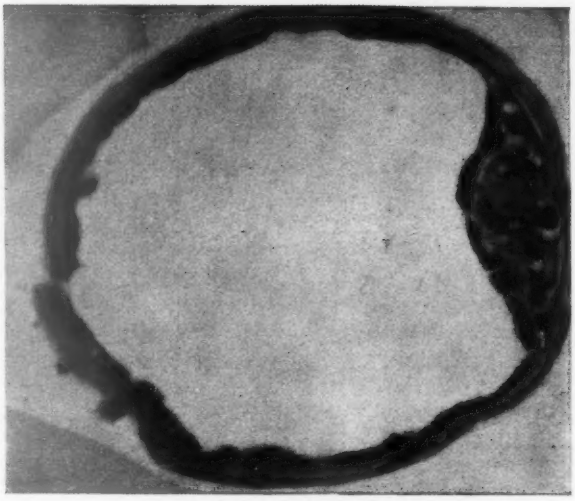

FIGURE 16 – *Blastocyst.*

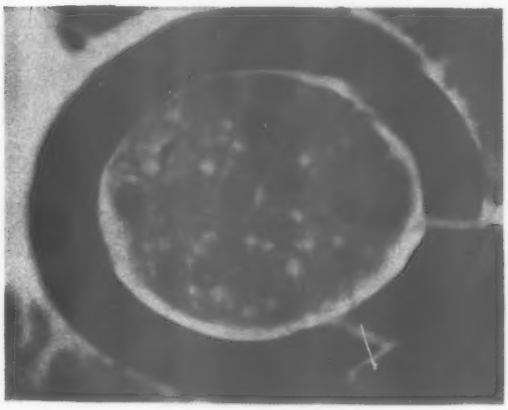

FIGURE 14 – *Morula.*

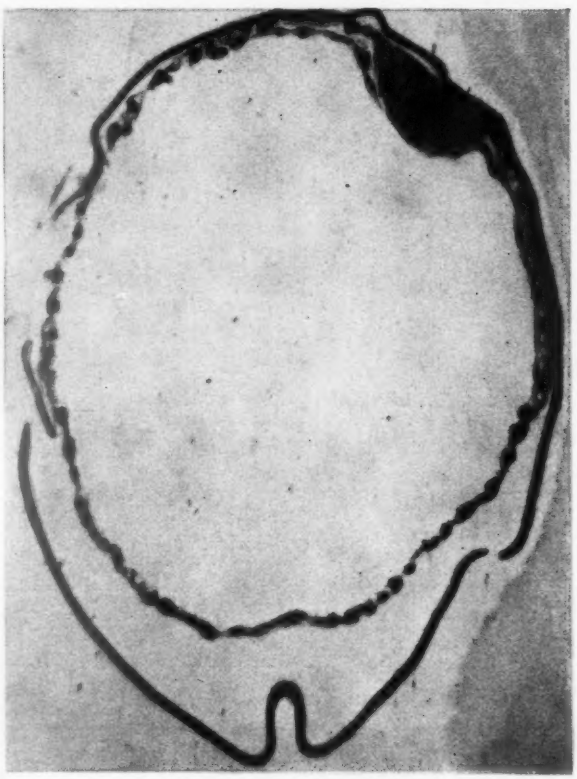

FIGURE 17 – *Blastocyst.*

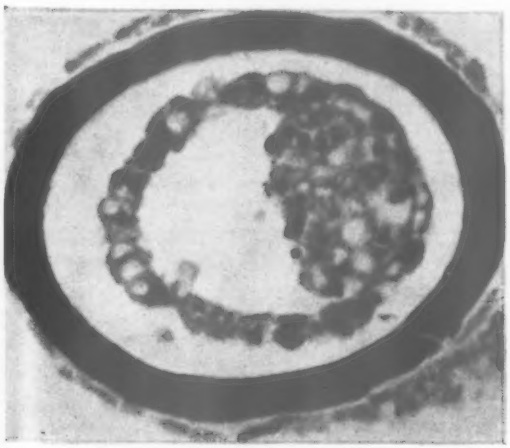

FIGURE 15 – *Blastocyst.*

FIGURES 7–17 – *Stained sections of cat eggs.* (*Figures* 7–14 × 700, *figure* 15 × 550, *figure* 16 × 450, *and figure* 17 × 270.)

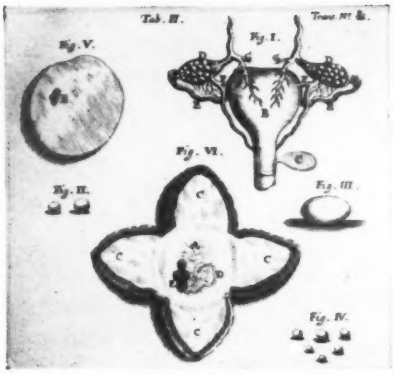

FIGURE 18 – *"Eggs to be found in all sorts of Females"* (*Kerckring*, 1672).

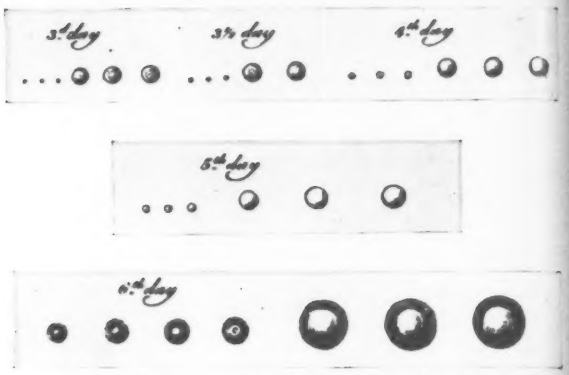

FIGURE 19 – *Rabbit eggs, natural size and enlarged* (*Cruickshank*, 1797).

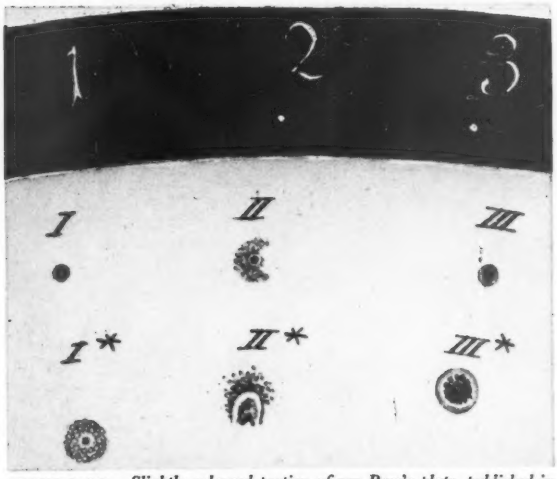

FIGURE 20 – *Slightly enlarged portion of von Baer's plate, published in* 1827. *Magnification on original plate: top row, natural size; middle row* × 10; *bottom row,* × 30.

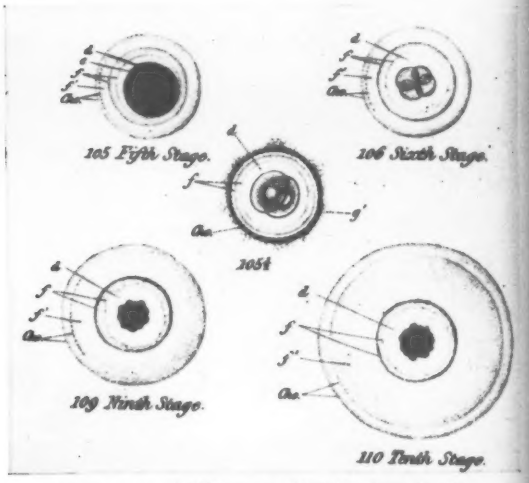

FIGURE 21 – *Rabbit eggs as depicted by Barry in* 1839.

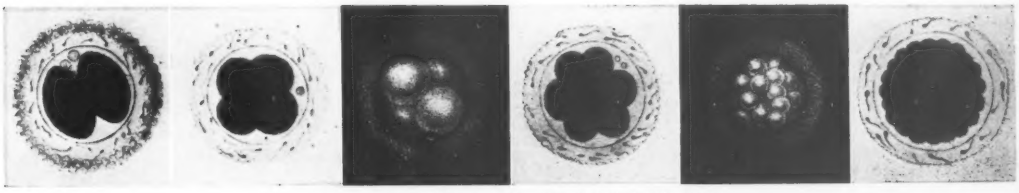

FIGURE 22 – *Dog eggs described by Bischoff in* 1845.

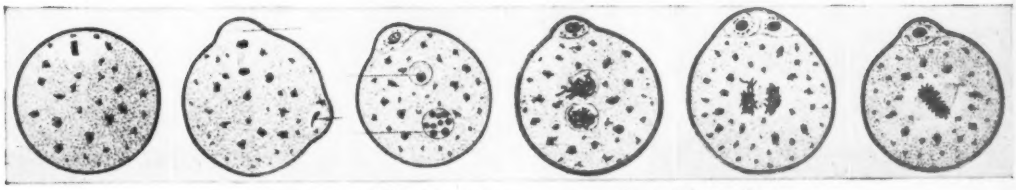

FIGURE 23 – *Fertilization in the mouse egg according to Sobotta,* 1895.

in each pronucleus; the new material is synthesized from cytoplasmic substrate, which is said to include mucopolysaccharide and acetalphosphatide [15]. Thus the pronuclei come to contain between them twice as much DNA as there is in a tissue-cell nucleus. The increase in DNA is attributable to the doubling of the chromosome number which occurs at this time. When the fertilized egg divides into a 2-cell embryo, each of the new nuclei will contain as much DNA and as many chromosomes as a tissue-cell nucleus.

One pronucleus may be noticeably larger than the other. In the rat and mouse, the volume of the male pronucleus is about two and a half times that of the female (figure 43). An adequate explanation for this rather curious feature is still lacking. In certain other animals, such as the rabbit and Libyan jird *Meriones libycus* (figures 32 and 31), a distinct disparity in size also exists, but for these animals it is not yet established whether it is the male pronucleus or the female pronucleus that is the larger. Sometimes the pronuclei are very nearly equal in size, as in the golden hamster *Mesocricetus auratus* (figure 33).

The nuclear membrane of tissue cells appears to be double except at the 'pores', where a single membrane exists. The double structure and the pores have been interpreted also in electron-micrographs of sea-urchin oocytes [1]. There is evidence that products of nuclear synthesis may reach the cytoplasm through the pores [2]. It has also been reported that nucleoli may be extruded into the cytoplasm in amphibian and mammalian oocytes, which is probably the same phenomenon in a different guise. The apparent development of vesicles in the membrane of the isolated 2-cell nucleus shown in figure 34 is consistent with the idea that the membrane is composed of two layers.

Cytoplasmic cleavage of the fertilized egg begins as the mitosis reaches telophase, and shortly after its completion nuclei reform from the chromosome groups. As in the genesis of the female pronucleus, nucleoli develop within each chromosome group as it disappears and a nuclear membrane becomes evident.

The 2-cell nuclei resemble pronuclei in usually having several nucleoli. The distribution of DNA is also similar except that there is a slightly higher concentration immediately round each nucleolus (figure 5). As cleavage proceeds through the 4-, 8-, and 16-cell stages, the nuclei diminish progressively in size (the volumes are approximately halved at each stage) and the nucleoli become fewer (figure 43). Concurrently, the concentration of DNA around the nucleoli increases very strikingly (figure 6); indeed, the arrangement comes to resemble that of the nucleolus-associated chromatin that was identified by Caspersson as part of the protein-synthesizing system of actively growing or secreting tissue cells. But there are two important differences: 8-cell nucleoli appear to have little or no RNA and the cytoplasm lacks the characteristically high concentration of this nucleic acid. These conditions develop later, in the implanted embryo; until implantation, extensive protein synthesis is evidently not a function of embryos in cleavage stages. If synthesis is in fact proceeding in the nuclei it may well be concerned with the production of the extra DNA which is required to maintain the diploid equivalent at each stage of cleavage.

THE CYTOPLASM

The egg cytoplasm, like the cytoplasm of most other body cells, is made up of the living substance or protoplasm and non-living nutrient materials constituting the yolk. The protoplasm of the typical body cell appears to consist largely of the endoplasmic reticulum or ergastoplasm and numerous small bodies, including the mitochondria (which contain most of the enzyme systems), the Golgi components, and the centrosome. Minute particles, the microsomes and related structures, with which cytoplasmic RNA appears to be almost exclusively associated, generally form integral parts of the ergastoplasm. Electron-micrographs of sea-urchin eggs show a similar pattern of organization [1], and it can reasonably be inferred for mammalian eggs.

Yolk takes different forms in different mammals. The yolk mass in the monotreme egg is very large and resembles that of the hen egg. The future embryo is represented by a small germinal disk on the surface of the yolk (figure 24). In the Australian native cat *Dasyurus* [17] and the armadillo *Dasypus* [19], the greater part of the yolk material is gathered in a distinctly bounded region at one pole of the vitellus; in *Dasyurus* the yolk composes a third body in the 2-cell egg and retains this form during early cleavage (figure 24). The yolk in placental eggs is scattered throughout the vitellus, either as numerous large droplets of fatty material, as seen in the cat egg (figures 8 and 12), and to a less extent in the eggs of the guinea-pig (figure 36), bat (figure 27), and several other animals, or as various forms of granules, particles, or minute aggregates. Sometimes the distribution is uneven

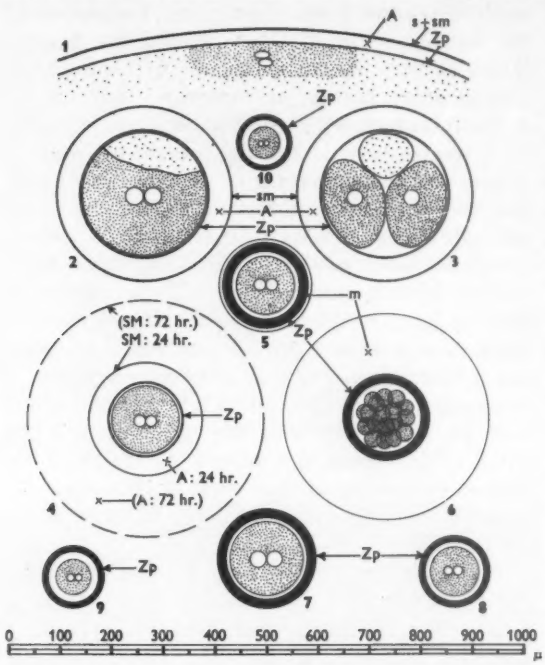

FIGURE 24 – *Sizes of mammalian eggs. Pronucleate eggs except Nos.* 3 *and* 6. (1) *The spiny anteater* Tachyglossus. (2) *and* (3) *The Australian native cat* Dasyurus. (4) *The American opossum* Didelphis, *at* 24 *hr after coitus; disposition of shell membrane and albumen layer at* 72 *hr also indicated.* (5) *and* (6) *Rabbit,* 10 *hr and* 72 *hr after ovulation respectively.* (7) *Sheep.* (8) *Man.* (9) *Golden hamster* Mesocricetus auratus. (10) *Field vole* Microtus agrestis. *A = albumen layer. M = mucoprotein layer. S = shell. SM = shell membrane. Zp = zona pellucida.*

and the egg has a distinct polarity. In general, the smaller the egg the less yolk it contains. Many eggs shed granular masses of yolk material from the vitellus into the perivitelline space, particularly during cleavage; this is especially well seen in the opossum *Didelphis* [16].

In frog and sea-urchin eggs there are quite large cytoplasmic stores of DNA, which are presumed to supplement the nuclear DNA as required at successive stages of cleavage. As yet, DNA has not been detected in the cytoplasm of mammalian eggs, and so the nucleic acid present must be considered as RNA only. The distribution in the rat has been found to be more or less uniform in the primary oocyte, in the egg during fertilization, and in the 2-cell embryo, but the RNA tends to gather about the nuclei in the later stages of cleavage. The total amount present is quite low until implantation of the embryo. Denser accumulations are said to characterize those blastomeres that will eventually form the inner cell mass of the blastocyst [15]. The ultra-violet absorption of living eggs suggests that higher concentrations of RNA occur in association with granular elements of the cytoplasm (figures 40 and 41); it is possible, however, that absorption is due, in part at least, to the presence of mononucleotides, which are contained very largely in the mitochondria. The similarity between the distribution of mitochondria and the arrangement of the red-fluorescent granules in eggs treated with acridine orange (figures 1–6) provides support for the idea that, under conditions such as those existing in living rat eggs, red fluorescence is caused by mononucleotides [4].

In the eggs of many non-mammalian species the centrosomes and their associated spindles and asters play an important and readily demonstrable role. At the approach of maturation, centrosome and aster divide into two parts which move towards opposite sides of the nucleus, the achromatic spindle develops between them, and thus an amphiaster is formed. The chromosomes become arranged on the equator of the spindle at the start of the first meiotic division. After the expulsion of the first polar body, the centrosome and aster remaining within the vitellus divide again and give rise to the spindle for the second meiotic division. When the second polar body has been formed, the vitelline centrosome and aster normally regress. The centriole introduced by the fertilizing spermatozoon is held to be responsible for the development of the centrosome, aster, and spindle required for the first cleavage division of the egg. At each subsequent cleavage, mitosis is preceded by division of centrosomes that are the descendants of the one that arose from the spermatozoon centriole. If, however, spermatozoon penetration does not occur and the egg is artificially activated, a centrosome and aster may reappear in the cytoplasm and serve the same functions as those normally fulfilled by the spermatozoon products. This is the case in parthenogenetic development.

Centrosomes and asters are more difficult to demonstrate in mammalian eggs, but their presence has often been reported in histological preparations. Mammalian-egg asters never seem to be as large or well developed as those in non-mammalian eggs. Spindles, however, are clearly visible, even in living eggs, provided these are examined by phase-contrast microscopy, when it is sometimes possible to see a suggestion of their fibrillar structure. Metaphase sipndles, such as those of the first and second meiotic divisions

(figures 26 and 28), and the telophase spindle before expulsion of the polar body (figure 25) are characteristically barrel-shaped or elliptical in form. By contrast, telophase cleavage spindles and meiotic spindles after polar-body emission are long and cylindrical (figures 9 and 27). Typically, a disk-shaped aggregation of granules (the 'central body') (figure 25) runs across the centre of telophase spindles—its significance is unknown. Meiotic chromosomes are relatively compact structures, lying mostly within the bounds of the spindle; cleavage chromosomes are more extended in form and project from the spindle, often to some distance (figure 29). The group shown in this figure is asymmetrical because of the very large sex chromosomes in the vole; in the polar view (figure 30) the remarkably large X-chromosome can be seen (the Y-chromosome in this preparation lay out of focus).

EGG MEMBRANES AND COVERINGS

As in tissue cells, the cytoplasm of the egg is bounded by a plasma membrane, which may reasonably be supposed to have the same general properties of permeability and active transport. In addition, the vitelline plasma membrane seems to display special features. When the fertilizing spermatozoon makes contact with the vitellus its head becomes firmly attached to the surface, and this is a prelude to its absorption into the vitellus; no attachment is made with subsequent spermatozoa, and their entry is thus precluded. The change in response to spermatozoon contact is the essential feature in the prevention of polyspermy. The precise role played by the plasma membrane in the process, however, is not known.

The vitellus is surrounded by a narrow fluid-filled perivitelline space, which is bounded externally by the transparent zona pellucida, a membrane that is most developed in the placental mammals (figure 24). It is composed of mucoprotein [12] and seems to lack distinctive structure, even when examined by electron-microscopy. The zona pellucida is laid down around the early oocyte, probably through the mediation of the surrounding follicle cells, from which fine processes retain connection with the vitelline surface until shortly before ovulation. After ovulation, the thickness of the zona pellucida in most animals does not alter noticeably unless and until blastocyst expansion occurs, when the membrane becomes extremely attenuated. In the cat, however, the appearance of eggs at successive stages shows that the thickness of the zona pellucida increases during cleavage, prior to expansion of the blastocyst (figures 7–14). In interpreting these figures it is necessary to take into account the effects of different fixatives upon the zona pellucida. Fixatives containing acetic acid tend to dissolve the membrane, and, depending upon the conditions of fixation, they cause rarefaction of its substance, as in figures 11 and 13, or diminution of its thickness, as in figure 12. The additional material is seemingly of the same composition and is presumably supplied through the secretory activity of the Fallopian tube. The process somewhat resembles the deposition of an albumen or mucin layer which, as will be noted later, characterizes the eggs of some mammals.

When a spermatozoon passes through the zona pellucida it leaves a narrow slit, which may be attributable to the action of a lytic agent carried by the perforatorium of the spermatozoon [3]. Permeation of the zona pellucida occurs again at a later stage—just before implantation, when long mobile cytoplasmic processes arise from the trophoblast cells at the pole of the blastocyst most distant from the embryo and grow out through the zona pellucida [10]. It is believed that these processes initiate implantation by establishing contact with the endometrium. For their passage through the zona pellucida they may well depend upon the action of a lytic agent similar to that carried by the spermatozoon.

In most of the mammals that have been investigated the zona pellucida becomes impenetrable to spermatozoa after the entry of the first. The change is known as the zona reaction; it is thought to be induced by some substance released from the vitelline cortex, as a result of spermatozoon contact, that alters the properties of the zona pellucida, rendering it resistant to the action of the hypothetical lytic agent. In the hamster egg the disappearance of distinctive cortical granules (marked by loss of surface light-refraction—figure 37) seems to be linked with the release of the zona-modifying substance. The zona reaction helps to protect the egg against polyspermy.

When the egg leaves the Graafian follicle at ovulation it is accompanied by many of the surrounding follicle cells embedded in a hyaluronic-acid matrix (figure 35). This investment, the cumulus oophorus, persists in the absence of coitus for about twelve hours in some animals (the rabbit and the rodents) but for perhaps only an hour or so in others (the ungulates). When the cumulus remains it represents a possible barrier

to the entry of spermatozoa, and it is probable that the enzyme (hyaluronidase) that they carry enables the spermatozoa to make their way through the cumulus.

In some animals the eggs become coated with a thick albuminous or mucinous layer as they pass down the Fallopian tube (figure 24). In addition, monotreme eggs are covered by a tough shell membrane; in the uterus they receive more albumen and finally a hard shell. In the marsupials *Setonix* [22], *Dasyurus* [17], and *Didelphis* [16] some further increments of albuminous material are added in the uterus, and these eggs also have a shell membrane. Among the placental mammals only the rabbit has been reported to possess the tubal mechanism for depositing an albuminous or mucinous coat about the egg (figures 21 and 24)—it is mucoprotein in this species [12]. There is some reason to believe that in the rabbit a further layer of somewhat different material is added in the uterus [11]. The mucinous coat of the rabbit's egg begins to be laid down seven to eight hours after ovulation; as it is impermeable to spermatozoa, its deposition is believed to be the main factor limiting the fertile life of the eggs.

Three of the forms of egg covering described—the zona pellucida, the cumulus oophorus, and the mucin layer—are, at least in the hamster, rat, and rabbit, porous to solutes of large molecular size, and probably allow free passage to the fat-soluble vitamins, the steroid hormones, and similar substances [6].

VITALITY OF THE EGG

Compared with the eggs of oviparous animals, the eggs of marsupials and placental mammals enjoy a large measure of protection and consequently have much better chances of giving rise to normal embryos. Nevertheless, a number of conditions and chemical and physical agents are known that may interfere with or prevent the normal production and development of eggs without necessarily causing injury or death to the maternal organism.

Either egg or spermatozoon may carry lethal genes, and if the same allele is present in both cells the resulting embryo degenerates before it can complete its development. Occasionally, too, dominant lethal mutations arise, and again extensive development of the embryo is precluded. The incidence of dominant lethal mutations is often ascribed to the effects of ionizing radiations, which may constitute part of the natural background or may derive from artificial sources. X-irradiation is specifically damaging to germ-cells, and in some animals, notably mice, whole-body irradiation may sterilize the ovaries without prejudicing the animals' chances of survival [20].

Embryonic death may also be attributable to abnormalities in the complex process of fertilization. Sometimes the male pronucleus fails in its prescribed function and the female pronucleus alone provides the chromosomes for the first-cleavage spindle. When the egg divides into a 2-cell embryo, the new nuclei each contain only half the normal number of chromosomes, and development that is initiated in this way is referred to as 'gynogenesis'. Alternatively, the female pronucleus may fail, and the embryo begins development with only the paternal chromosomes: this is termed 'androgenesis'. Both forms of development seem to be inconsistent with protracted embryonic life. Sometimes, in spite of the protective devices, polyspermy occurs—two spermatozoa take part in fertilization, and so the embryo comes to have a three-fold chromosome complement. This, too, as far as is known today, precludes full normal development, and the same can be said also for the irregularities in chromosome number that follow major disturbances of oocyte maturation [9].

Many functions of the female genital tract are closely controlled by hormone balance and are affected also by the health and nutritional status of the animal, as well as by a wide range of administered drugs. Eggs and early embryos, however, have a period of free existence within the genital tract—from the time of ovulation until the implantation of the embryo in the uterus—and during this period they seem to be immune to most of these influences. Special susceptibilities do exist, however, and certain agents such as podophyllotoxin are known to be more damaging to the free-living embryo than to most other body cells [25].

The indifference of the egg to environmental change *in vivo* suggests that its vitality should be sufficient to sustain the cell when removed to other situations, and indeed there is ample evidence that this is so. In several species, eggs, as oocytes or as early embryos, can survive transfer to the genital tract of another animal [26]. Unfertilized rabbit eggs can tolerate storage *in vitro* at 10° C for as long as 96 hours [13], and fertilized rabbit eggs have often been cultured *in vitro* through cleavage to blastocyst formation. Mouse embryos have developed from morulas to

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FIGURE 25 – *Early telophase, first meiotic spindle (rat). The central body is very distinct.*

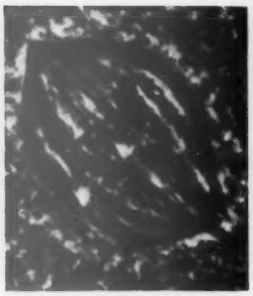


FIGURE 26 – *Metaphase, second meiotic spindle (field vole).*

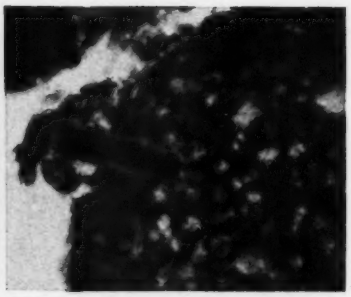


FIGURE 27 – *Late telophase, second meiotic spindle (bat).*

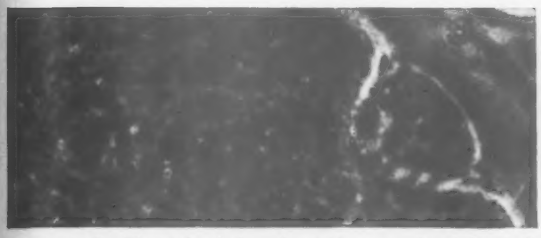
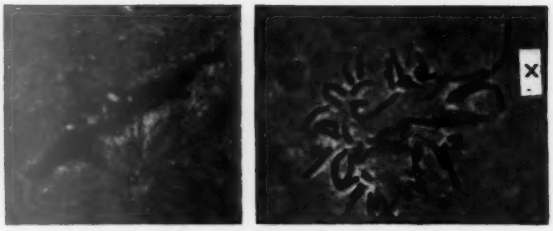
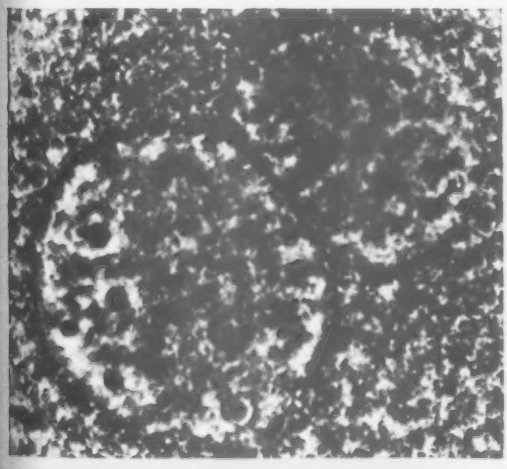


FIGURE 28 – *First polar body and metaphase second meiotic spindle (golden hamster).*



FIGURES 29 and 30 – *First cleavage spindle (field vole), showing X-chromosome.*



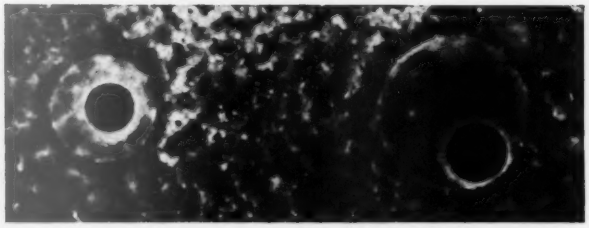


FIGURE 31 (*above*) – *Pronuclei of the Libyan jird.*

FIGURE 32 (*left*) – *Rabbit pronuclei.*

FIGURE 33 (*below*) – *Pronuclei of the golden hamster.*

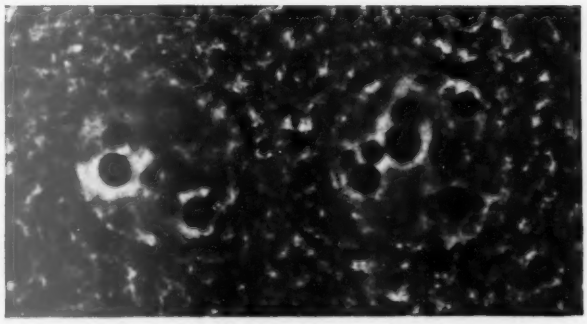


FIGURE 34 (*left*) – *Nucleus expelled from ruptured 2-cell rat egg. The apparent vesicles in the nuclear membrane are visible.*

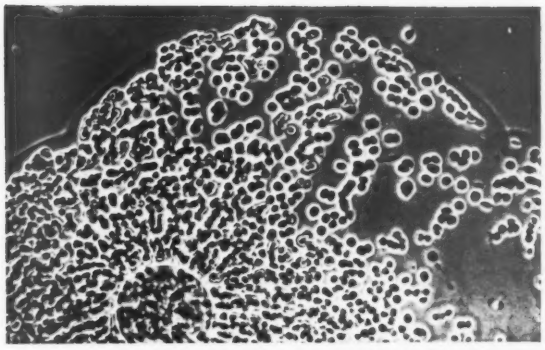


FIGURE 35 – *Rat egg surrounded by the cumulus oophorus; follicle cells embedded in a hyaluronic-acid matrix.*

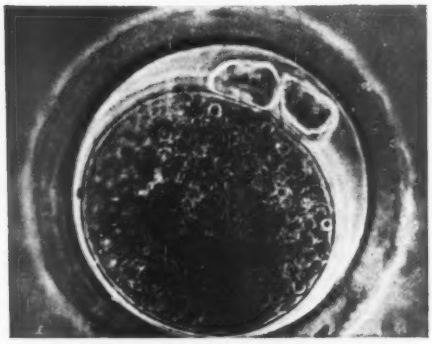


FIGURE 36 – *Guinea-pig egg undergoing fertilization. Note droplets of yolk material in the cytoplasm.*

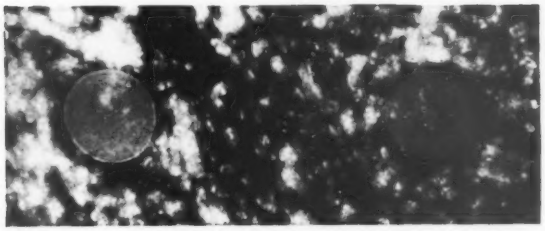


FIGURE 37 – *Loss of light refraction at the surface of a penetrated hamster egg (right).*

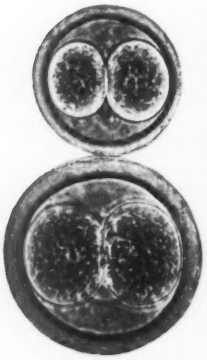


FIGURE 38 – *Normal and 'giant' eggs of the cotton-rat.*

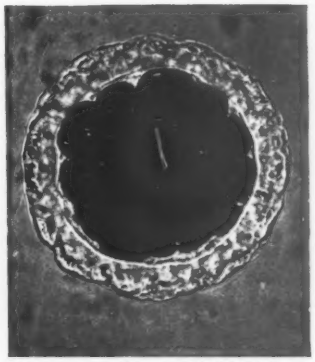


FIGURE 39 – *Dog morula (cf. Bischoff's sketch, figure 22).*

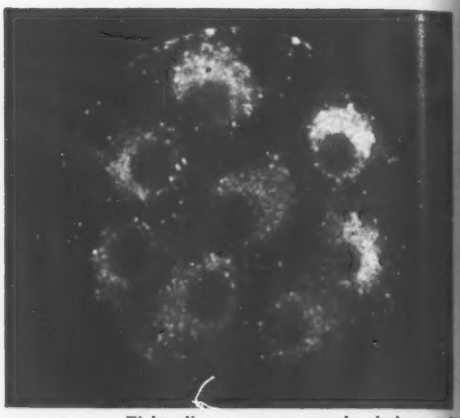


FIGURE 40 – *Eight-cell rai egg as seen by dark-ground illumination, showing distribution of granules.*

FIGURE 41 – *Ultra-violet absorption by an 8-cell rat egg, showing distribution of nucleic acids.*

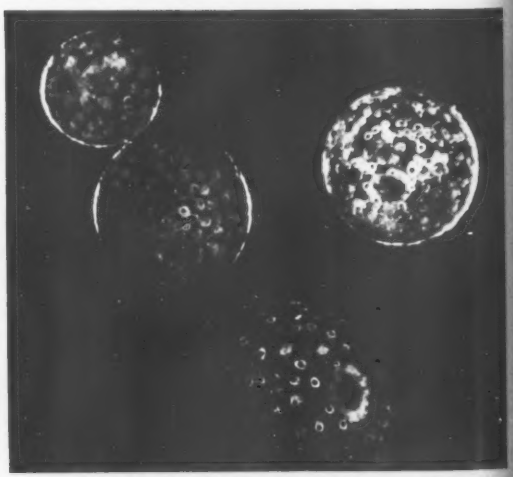


FIGURE 42 – *Dog blastocysts, as seen by dark-ground illumination.*

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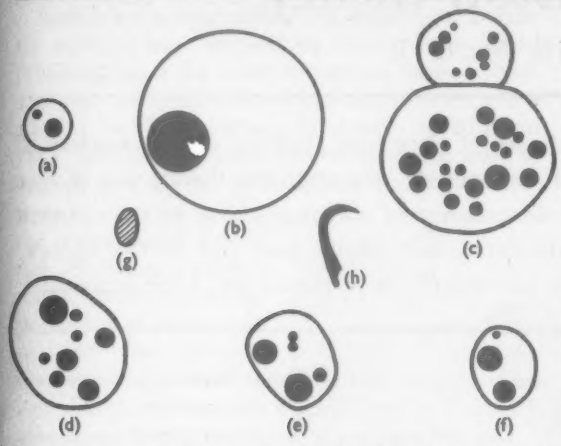

FIGURE 43 – *Relative nuclear size (rat) in* (a) *early primary oocyte,* (b) *late primary oocyte,* (c) *egg in late stage of fertilization,* (d) *2-cell egg,* (e) *4-cell egg,* (f) *8-cell egg,* (g) *follicle cell, and* (h) *spermatozoon.*

blastocysts when kept in culture in an artificial medium [24] and on transfer to a host animal have given rise to normal young [18]. Mouse eggs have also been shown capable of normal development even after being held as isolated tubal oocytes at a temperature of $-10°$ C for $3\frac{1}{2}$ hours [23], or as primary oocytes in excised pieces of ovary at a temperature of $-79°$ C for six weeks [21]. There is no doubt that, under the appropriate conditions, manipulation of eggs need involve no detrimental effects, and in view of their tolerance to storage and transfer eggs are becoming recognized as invaluable subjects for studies, not only in investigations on fertility but in cytology, genetics, and immunology.

ACKNOWLEDGMENTS

We are indebted to Mr M. R. Young for the colour photography of the fluorescent eggs (figures 1–6), which was made possible by a technique that he developed for photographing the egg sections (figures 7–17), also in colour, and for the ultra-violet photomicrograph of the rat egg in figure 41. Our thanks are due also to Dr Ruth Deanesly for the section of the bat egg shown in figure 27. Miss Heather Speer drew the diagrams appearing as figures 24 and 43. Figures 26, 29, and 30 are from the 'Journal of Anatomy'; figure 28 from the 'Journal of the Royal Microscopical Society'; and figure 37 from 'Experimental Cell Research'.

HISTOLOGICAL TECHNIQUES

Figures 7, 10. Zenker formol; Weigert H and E.
Figure 8. Flemming; Heidenhain haematoxylin.
Figure 9. Zenker; Heidenhain H and E.
Figures 11, 13. Zenker formol with acetic acid; Masson trichrome.
Figure 12. Zenker formol with acetic acid and post-osmication; Weigert haematoxylin.
Figures 14–17. Bouin; Weigert H and E.

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The phlogiston theory

DOUGLAS McKIE

The phlogiston theory was the first general theory of chemistry, uniting a wide variety of observations that were otherwise apparently disconnected. Although the theory was in fact erroneous, it materially contributed to the early progress of chemistry, and its importance is too often underestimated. This article describes the origins and rise of the theory, and its eventual replacement as the defects in Lavoisier's 'new chemistry' were remedied.

The phlogiston theory has always attracted those interested in the history of chemistry. There are good reasons for this: the theory arose in the modern period—that is, since 1500; it was the first general theory of chemistry; it was accepted for about a hundred years and by chemists of the eighteenth century who are still honoured as among the founders of our science; and it became inadequate, and was therefore abandoned, only about a hundred and seventy-five years ago. We may gauge its importance from the fact that as late as 1783 Lavoisier found it necessary to devote a critical study of some thirty-four pages to it in the *Mémoires* of the *Académie Royale des Sciences*; this detailed criticism, '*Réflexions sur le Phlogistique*', is comparable in historical significance to Newton's refutation of the vortex system of Descartes in the *Principia*.

The origin of the theory may in a very limited sense be detected in the speculations of the ancient Greeks on the composition of matter. Empedocles in the fifth and Aristotle in the fourth century B.C. included fire among the four elements that made up the world; that element was obviously set free in burning and often accompanied by its concomitant flame. The slight change in the theory of the chemical composition of matter made by Paracelsus in the early part of the sixteenth century involved not the abandonment of the four-element theory but the further supposition that the more immediate elementary constituents of substances, those that could be obtained by analysis, were the three 'hypostatical' principles or elements, salt, sulphur, and mercury. In this way the ancient element of fire lived on in the form of sulphur and no fundamental change had been made in the age-old beliefs about the composition of matter.

The idea of an elementary fire as a component of combustible bodies had thus been long ingrained in chemical thought; and, as we must admit, it is very naturally supposed even today, by those who are not better informed, that burning is the release of some 'fire-stuff' from a combustible.

This old and vague notion received more precise treatment from Johann Joachim Becher (1635–82), a German, born in Speyer, sometime professor of medicine in the University of Mainz but more interested in chemistry. Becher is an interesting figure. He lost his father in the Thirty Years War; as a boy he had to give lessons in reading and writing to maintain his mother, his brothers, and himself, as his family's means had been lost. He lived and worked at various times in Munich, in Vienna, in Haarlem, and in Cornwall, where there are traditions of his work. He died in 1682, probably in London—there is some evidence that he was buried in the church that is now St James's, Piccadilly. Becher published many books, and in one of these, the *Physica Subterranea* (Frankfurt, 1669, and later editions), he rejected the theory of Paracelsus. He held instead that there were three elements, air, water, and earth, although air was no more than an agent or instrument moving and impelling water and earth into 'mixts' (we would say compounds), the varying proportions of elementary earth and water occurring in these 'mixts' accounting for the diversity of substances in the world. There were, moreover, three earths: first, *terra lapidea*, fusible and vitrifiable; second, *terra pinguis*, fatty, oily, combustible, sulphureous; and third, *terra fluida* or *mercurialis*, fluid, subtle, volatile, mercurial. Metals and minerals in general were composed of these three earths in different proportions. The *terra pinguis* can readily be recognized as the old fire element in a new guise; it was presently to become, through the advocacy of Stahl, the principle or element of inflammability and to receive the name of phlogiston. It may be recalled here that, from the time of Jabir ibn Hayyan, Muslim chemistry had taught that metals were composed of two elements, namely sulphur and mercury.

Becher's teaching made little impact on chemistry until it was adopted by Georg Ernst Stahl (1660–1734), a far more important figure. Stahl also was a German, born in Anspach; he was a student in Vienna, where he graduated M.D. in 1684; and he is remembered today for his work in biology and physiology as well as for his contributions to chemistry. On the invitation of Friedrich Hoffmann, professor of medicine in the university of Halle and perhaps the greatest German physician of his age, Stahl became the other professor of medicine in Halle (1694–1716); later he was physician to King Frederick William I of Prussia, father of Frederick the Great. He died in Berlin in 1734. Among his many books his *Fundamenta Chymiae* (Nürnberg, 1723) is chemically most important; earlier he had published a reprint of Becher's *Physica Subterranea* with an extensive commentary called *Specimen Becherianum* (Leipzig, 1703, and later editions); and some other interesting chemical books, including his *Experimenta, Observationes*, etc. (Berlin, 1731), which is especially interesting for the phlogiston theory, indicate the extent of his chemical studies.

FIGURE 1 – *Lampoon of Joseph Priestley as 'Doctor Phlogiston'. The publication of this in the 'Attic Review' shows that the educated public had some acquaintance, at least, with the phlogiston theory.*

In adopting and extending Becher's views, Stahl emphasized the idea that phlogiston was released in all combustions, since it was present in all combustible bodies. Since it was contained also in metals as a common principle, it was similarly set free when they were calcined, the differences between the metals being due to the differences between their calces. Highly combustible substances, such as charcoal, oils, and fats, were rich in phlogiston, and less combustible substances had less of it. Stahl showed, moreover, that the calx of a metal could be restored to its former metallic state by heating with a substance rich in phlogiston, such as charcoal, thus demonstrating that the principle of inflammability could be transferred from one substance to another; and he had also shown that combustion and calcination were essentially similar changes. For these discoveries he was long afterwards hailed by Lavoisier as one of the patriarchs of chemistry and as one who had effected a kind of revolution in that science.

Stahl supposed also that the phlogiston set free in combustion and in fermentation passed into the atmosphere, and so air contained much of it. Air was necessary in ample quantity for combustion, because a limited amount of air could absorb only a limited amount of phlogiston. From the air phlogiston entered into the life of plants and thence into that of animals, and there was thus a kind of phlogiston-cycle in Nature, to all three kingdoms of which—animal, vegetable, and mineral—it was common.

Since sulphur on burning gave vitriolic acid, it followed that sulphur was composed of phlogiston and vitriolic acid; for this Stahl produced what he considered to be an experimental demonstration of the correctness of the theory. Sulphur on combustion gave vitriolic acid; with an alkali, salt of tartar (potassium carbonate), he converted the acid into vitriolated tartar (potassium sulphate); he then heated this with powdered charcoal (largely phlogiston) and, on treating the solid product with vinegar, he obtained milk of sulphur. By this series of changes he had restored to the vitriolic acid the phlogiston removed from it in the first reaction and had thus reconstituted the sulphur.

Such was the phlogiston theory when Stahl died in 1734. In the fifty years that followed it spread outwards from Germany and was accepted by the chemists of Europe—by Black, Priestley, Cavendish, Scheele, Bergman, Macquer, Guyton de Morveau, Berthollet, and Fourcroy, to name only a very small number of them. In those fifty years chemists made many discoveries, particularly the discovery of 'airs', as the gases were then called. To these the phlogiston theory proved most accommodating. When Cavendish, for example, isolated 'inflammable air' (hydrogen) in 1766, he was satisfied that it came from the metals and not from the acids with which the metals had reacted; and later many chemists, including Cavendish for a time, regarded this 'inflammable air' as the phlogiston released from the metals. Still later, in 1783, further new, strong experimental evidence was afforded in favour of the theory, when Priestley found that 'inflammable air' passed over heated metallic calces restored them to their former state of metals. Phlogiston in an almost pure state had been restored to the calx and had reconstituted the metal.

The isolation by Priestley in 1774–75 of the new 'air' that was later called oxygen was one of the most significant discoveries in this period; it was soon enfolded within the phlogiston theory. When Priestley noted that this new 'air' enhanced the burning of a candle and other combustibles and that it maintained animal respiration much longer than common air, he quickly pointed out that common air was constantly being contaminated with phlogiston released from fires, fermentation, putrefaction, and respiration, whereas the properties of the new 'air' clearly showed it to be uncontaminated with phlogiston, and so he named it 'dephlogisticated air'.

In combustion and respiration in common air, both processes ceased after a time, leaving a residue no longer fit to maintain them; in respiration and in certain combustions it was necessary to remove by milk of lime or lime-water the 'fixed air' (carbon dioxide) that Joseph Black had differentiated from common air in 1754–56; but in all cases the final residue was supposed to be common air saturated with the phlogiston given off in combustion or in respiration, and so it was named 'phlogisticated air' (nitrogen).

While the phlogiston theory readily explained these new facts, there was one long-established experimental observation in apparent contradiction with it, namely the gain in weight of metals on calcination when, according to the theory, phlogiston was set free. Although the principle of the conservation of mass in chemical change was not yet explicitly formulated, gain in weight with concurrent loss in substance was not acceptable in chemical thought. Many ingenious explanations were put forward to explain this apparent anomaly. Guyton de Morveau supposed that phlogiston was lighter than the lightest substance known and that it therefore buoyed up the metals of which it was a component; they became heavier when it was set free in calcination. There were some who supposed that phlogiston had a negative weight, being repelled from the centre of the Earth towards the circumference; whereas other kinds of matter gravitated towards that centre, phlogiston levitated from it.

In a series of researches that began in the 1770s Lavoisier showed that the gain in weight of metals on calcination could be quantitatively accounted for by their combination with a part, about one-fifth, of the common air; that this part, to which he subsequently gave the name of oxygen, was similarly active in combustion and in respiration; that the other part, about four-fifths (later known as nitrogen), was inactive in all three processes, extinguishing fire and asphyxiating life; and that, when combustion took place in oxygen, there was no residue of 'phlogisticated air', the oxygen being consumed 'to the last bubble'. (*jusqu'à la dernière goutte*). His work failed, however, to convince his contemporaries for almost ten years; and when he attacked the phlogiston theory in 1783 he was without any supporter. There were good reasons, of course, why the chemists of that time did not wish to abandon their theory, which was a general systematizing theory of chemistry, for a new one that was limited in its application. One of these reasons was very simple. It concerned the combustion of 'inflammable air'. According to Lavoisier's theory, all combustion was combination with oxygen, but attempts both by himself and others to isolate a product of this particular combustion failed. While neither theory was of value on this important point, the phlogiston theory could at least satisfactorily explain the difference between the products of the reaction between an acid and a metal, when 'inflammable air' was evolved, and of the reaction between the same acid and the calx of that metal, when, of course, 'inflammable air' was not evolved. To the phlogiston theory a metal consisted of its calx united with phlogiston, and 'inflammable air' was produced in the first reaction by the realease of that phlogiston; there could be no evolution of

'inflammable air' in the second reaction because the calx was the residue of the metal after it had lost its phlogiston. For this difference Lavoisier could give no explanation; the composition of acids was unknown, and Lavoisier regarded them as oxides; the composition of water was likewise unknown.

In June 1783, however, Lavoisier heard from Blagden, then on one of his frequent visits to Paris, that Cavendish had burnt a mixture of 'inflammable air' and 'dephlogisticated air' and that he had obtained water from this combustion. Lavoisier appears to have realized the significance of this observation; he made a crude experimental verification of it at once and advanced the explanation that water was a compound of these two gases. The difference between the two reactions referred to in the preceding paragraph could now be explained, since water could be regarded as taking a part in them. In the former, the water could be considered as decomposing, its 'inflammable air' being evolved and its 'dephlogisticated air' or oxygen combining with the metal to give the calx (the term oxide had not yet been coined), which then united with the acid to produce the salt; in the latter reaction it was a simple case of the calx combining with the acid to give the salt. Lavoisier began to gain some supporters, for a fundamental difficulty in his theory was now resolved.

There were, however, other difficulties, far from trivial, which were more adequately explained by the phlogiston theory. For instance, there appeared to be two kinds of 'inflammable air', which Lavoisier differentiated as 'light inflammable air' (hydrogen) and 'heavy inflammable air' (carbon monoxide). The composition of the latter was not understood; it gave 'fixed air' or carbonic acid on burning. It proved a baffling problem for the new theory, but it was explicable in terms of phlogiston. Priestley himself made considerable use of it. He had obtained 'inflammable air' (carbon monoxide) when he heated finery cinder (iron oxide) with charcoal. He argued that, since the new theory considered 'inflammable air' as a component of water, it could be produced only in a reaction where water was present; and, he pointedly added, the new theory itself excluded water from the composition of these reactants, taking finery cinder to be an oxide, containing only iron and oxygen, and admitting no water in the composition of charcoal, which was a substance produced at the highest degree of heat. The old theory, on the other hand, regarded finery cinder as having imbibed water in place of its phlogiston and it also supposed that water was a constituent of all 'airs', so that the 'inflammable air' was produced by the union of the water from the finery cinder with the phlogiston from the charcoal. This reaction remained incomprehensible to the new theory until Cruickshank, in 1801, showed that Lavoisier's 'heavy inflammable air' was not hydrogen but an oxide of carbon, which he named 'gaseous oxide of carbon'. This interpretation was slowly accepted, although it failed to convince Priestley that he was wrong; he remained an adherent to the phlogiston theory until his death in 1804.

There were many attempts to adjust the phlogiston theory to the new discoveries in chemistry, particularly by Gren in Germany, and much ingenuity was spent for this purpose. In general, these were concerned with the problem of the heat and light evolved in combustion, which effects were not satisfactorily explained on Lavoisier's theory. There had been many earlier adjustments of the theory: Kirwan had identified phlogiston with 'inflammable air' and Macquer had considered it to be the matter of light; but, although chemists were accustomed to depart from the original theory as propounded by Stahl, it seemed that the most satisfactory way of explaining what Lavoisier's theory did not explain was to suppose that a combustible contained phlogiston and that oxygen gas contained caloric or the matter of heat, so that in the process of combustion, while the oxygen combined as usual with the combustible, the phlogiston from the latter combined with the matter of heat from the oxygen to give the fire and light that were so often the products of ignition. In one form or another the phlogiston theory survived in the background of the chemical thought of the early nineteenth century. This should cause us no surprise; for it was still customary, and long remained so, in chemistry to include the imponderables, heat and light, among the elements of which matter was composed, and it was fundamental in physics, for good reasons, to consider that heat was material. The difficulties inherent in the new chemistry were not resolved until the mid-nineteenth century, when the nature of heat had become clear, and when energy, and its changes and transformations, were at last understood. It is interesting to observe that the great chemists of the eighteenth century did not abandon the phlogiston theory as soon as an alternative was produced, but made many skilful adjustments of that theory to fit, for as long as possible, the changing pattern of discovery.

Crystalline rocks and the passage of time

J. SUTTON

The determination of the order of the strata occurring in the Earth has been accomplished, in the main, by the use of the fossil-bearing sedimentary rocks. This method cannot be applied to the Pre-Cambrian rocks, which are devoid of usable fossils, nor to the crystalline rocks generally. This article describes methods that have been devised for such rocks.

Since the early nineteenth century, when William Smith first showed how the relative ages of sedimentary rocks could be determined from the fossils they contain, geologists have been elaborating a stratigraphical succession covering geological time from the Cambrian to the present day. Once the position of a rock within this stratigraphical column has been established, the geological events that have left a record in that rock can be placed more or less precisely in their correct chronological setting. In this way the distribution of land and sea, the position of the principal mountain chains, and the changes in climates in the past have been gradually elucidated. It is, naturally, geological events that have taken place at the surface of the Earth that are best recorded in the sedimentary rocks and in the interbedded volcanic rocks, although these rocks also provide indirect evidence by which earth movements and igneous activity originating at depth may be dated. Indeed, it is true to say that the greater part of our knowledge of the distribution of earth movements through geological time since the Cambrian, when usable fossils first appeared, comes from the evidence supplied by sedimentary rocks.

Such evidence, however, is fragmentary and hard to come by, for it requires that one should find datable deformed rocks covered by slightly younger datable rocks unaffected by the deforming movements. The age of an intrusion can be approximately determined in an analogous manner; thus the Shap 'granite' of north-west England was formed after the Silurian, since it cuts beds of that age, and before the time when the overlying Lower Carboniferous beds were deposited. Evidence of this kind is even more difficult to find in the more highly metamorphosed parts of mountain chains and is, of course, totally lacking in the unfossiliferous Pre-Cambrian.

The classical methods of stratigraphy need to be supplemented if one is to comprehend the history of the changes that have gone on at depth within the crust of the Earth throughout geological time. The three great groups of events concerned in such changes are the arrival of igneous material, the production of metamorphic rocks, and the deformation of the crust.

The absolute dating of the crystalline rocks in which such changes are recorded has been possible since Rutherford saw that the breakdown of radioactive minerals offered a way of measuring the time that had elapsed since they were formed. A quite different approach has been the attempt to establish the relative ages of assemblages of minerals in metamorphic rocks, or of successive sets of geological structures formed by earth movements. This can be done by detailed examination of the anatomy of metamorphic terrains. A third possibility consists of dating events which took place at depth by considering the effects they produced at the surface on sedimentary rocks whose age can be established by classical means. It is with applications of the second method that we shall be mainly concerned in this article, but first we may consider some matters connected with absolute age determinations.

THE ABSOLUTE AGES OF ROCKS

The techniques so far used, such as the measurement of the uranium : lead, rubidium : strontium, or potassium : argon ratios are tedious and costly, and it is plain that each determination should be made to yield as much information as possible. A. Holmes [1] and more recently K. I. Mayne, R. St J. Lambert, and D. York [2] have shown that curves giving the length of time represented by any part of the stratigraphical table, from the Cambrian on, can be drawn from comparatively few measurements. Mayne and his co-workers employed 17 measurements of material which could be placed in the conventional stratigraphical table, and used these measurements to show the absolute ages of the geological divisions in question. The material came from widely separated parts of Europe and America. Pre-Cambrian rocks naturally could not be dealt with in this way,

for there is as yet no purely geological means of placing Pre-Cambrian rocks in a chronological sequence that would be valid over so large a region. The dating of the Pre-Cambrian has largely been achieved by mapping out the major structural divisions in each area, and by finding the age of minerals believed to have formed when the major structures same into being during the succession of Pre-Cambrian periods of orogeny[1].

The recognition of the sequences of events which occurred during such an orogeny and which are recorded in the crystalline rocks, and their correlation so as to produce a world-wide geological succession extending back into Pre-Cambrian time, is a fascinating task on which many are now engaged. Much has already been done, and some questions, such as the distinction between granites formed at the height of the mountain-building movements and those formed in the closing stages, are now reasonably well understood in a qualitative way. An important advance is the recent work in California by Evernden, which, for the first time, shows how much time elapsed while a succession of granites was intruded during a single cycle of mountain-building. This result was obtained on material from a geologically young mountain chain, but it is to be hoped that, as techniques improve, similar work will be undertaken on the granites of the older chains. It is of interest that Evernden was able to confirm the sequence of intrusion that had already been deduced from observations in the field, and that the absolute dating confirmed in every case the succession indicated by geological reasoning.

THE GEOLOGICAL DATING OF CRYSTALLINE ROCKS

We may turn now to some examples of sequences of events deduced on geological grounds from observations made in crystalline rocks in Scotland, where few determinations of absolute age have been made. In Scotland there are preserved fragments of at least three mountain chains. In the Outer Hebrides and along the north-west seaboard of the mainland the Lewisian gneiss retains a record of two Pre-Cambrian orogenies, and to the east there are the extensive outcrops of the Moine and the Dalradian Series which were folded and metamorphosed during the Caledonian orogeny and which form part of a chain of crystalline rocks extending from Norway to western Ireland. The detailed maps published by the Geological Survey, and the work which numerous investigators are carrying out at the present time, show that for each of these orogenies there can be made out a succession of phases during which rocks were metamorphosed, deformed, or cut by intrusions. Some examples may be more helpful than a general discussion.

The Lewisian rocks along the west coast occur in two rather different conditions [3, 4]. In certain tracts, for example between Scourie and Gruinard, the gneisses frequently strike to the north-east and are commonly very highly metamorphosed; the gneissose assemblage as a whole is cut by fresh dolerite dykes. In other districts, such as that between Loch Laxford and Cape Wrath, the dolerites have also been metamorphosed, and both they and the surrounding gneisses have been affected by renewed earth movements, with the result that the gneisses now strike north-west; they are invaded by numerous granites and pegmatites which can be shown to be later than the dolerites.

It would appear that this arrangement is the product of two separate periods of mountain-building. During the first period, which has been called the Scourian, metamorphism occurred and the rocks acquired their north-easterly strike. Then followed a phase when dolerite dykes were intruded. Subsequently parts of the Lewisian were affected by a second, or Laxfordian, orogeny during which further metamorphism and deformation took place. Those parts of the Lewisian which escaped the effects of this later period remain in the condition produced by the earlier orogeny. The key to the geological history is provided by the swarm of dolerite dykes intruded between the two movements; the dykes are unaltered where the Scourian orogeny alone has affected the rocks, but are metamorphosed where the effects of the Laxfordian orogeny have been superimposed on those of the Scourian.

Two orogenies of Pre-Cambrian age have been identified on very similar evidence by Noe-Nygaard [5] in west Greenland, and comparable examples of repeated metamorphism have been reported from the Alps, where rocks first metamorphosed during the Palaeozoic Hercynian orogeny have been re-metamorphosed during the Alpine movements of the Tertiary Period. Thus, in the Silvretta region of the eastern Alps a swarm of dolerites was intruded between the two movements just as in the previous examples [6].

An interesting picture emerges if one examines

[1] Orogeny is the phase in mountain-building during which the accumulated sediments are compressed, giving rise to folds and faults.

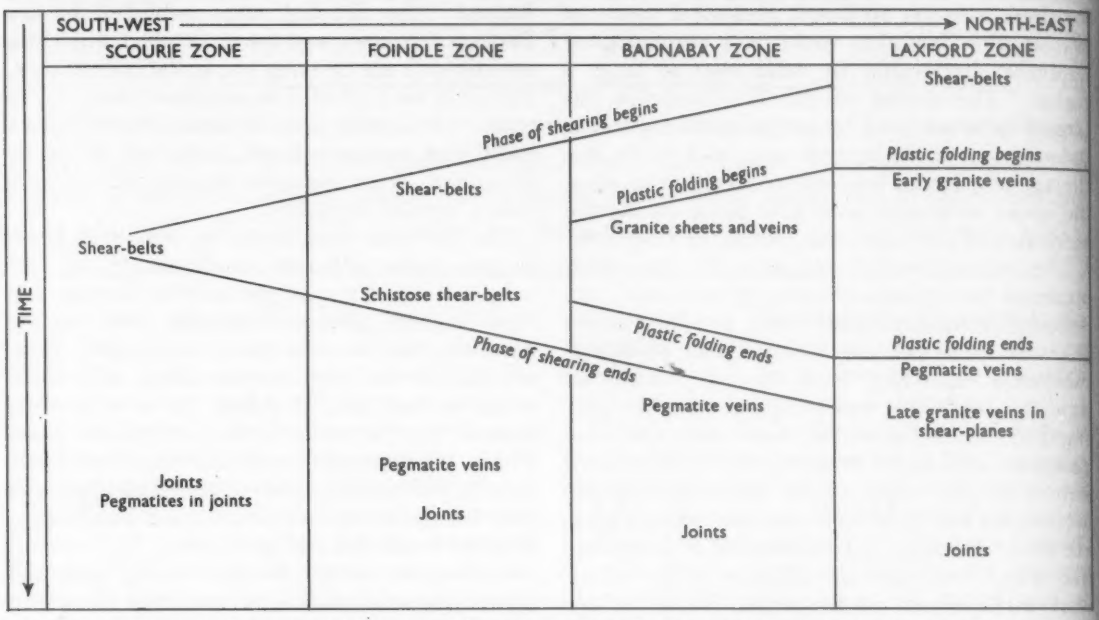


FIGURE 1 – *Sequences of events established in Lewisian rocks near Loch Laxford, Sutherland.* (*After Sutton and Watson* [4].)

the Lewisian of western Scotland near the margin of an area affected by the later Laxfordian orogeny. The results of such an examination are summarized in the accompanying table (figure 1). Each column records a sequence of events made out in one zone—the zones are 12 km wide in all and are arranged in series from the least altered (in the south-west) to the most altered (in the north-east). Laxfordian movements, metamorphism, and migmatization were most pronounced in the Laxford zone in the north-east and progressively diminished towards the Scourie zone some 12 km further south-west. The train of events set in motion by the Laxfordian orogeny did not begin at the same time in every place, but it seems that the Laxfordian metamorphic front was diachronous, in that it apparently worked its way southward through the crust and then retreated again to the north. The Scourie zone had the simplest history and the Laxford zone the longest and most complicated. In each zone the onset of the movements was marked by the formation of shear-belts—long strips of rock in which the gneisses were ground down while wedges of crystalline rock moved past. As the metamorphism developed, shearing gave place to folding in the two most northerly zones, while movement along shear-belts was still taking place further south, where the metamorphism was less intense. Towards the close of the movements, shearing once more occurred everywhere. Granitic rocks of various kinds had begun to appear during the phase of plastic movement. In the north-eastern zones, shearing movements were still continuing when the last of these granites or pegmatites were formed, but at Scourie the movements had already stopped when the latest pegmatites were intruded. The variations across the relatively narrow zones of the Loch Laxford region show how rapidly the time relations of igneous activity, metamorphism, and deformation may change, and illustrate the complexities of the histories recorded in crystalline rocks.

A. Holmes, H. A. Shillibeer, and J. T. Wilson [7] have determined the age of felspars from Laxfordian pegmatites by the potassium: argon method and found it to be 1090 ± 70 million years. In view of later findings that felspars during their lifetime may lose up to 30 per cent of the argon resulting from radioactivity [8], the age of the Laxfordian orogeny is likely to be rather greater. The Lewisian, with its two well-demarcated structural patterns, would appear to be an ideal formation in which to relate absolute ages to time sequences established on structural and metamorphic evidence. No successful Scourian determination of age has been published up to the time of writing. Holmes and his colleagues have compared the sequence seen near Loch Laxford with sequences in rocks for which similar ages had been

FIGURE 2 – *Cleavage planes in folded argillaceous schists, Ross of Mull.*

FIGURE 3 – *Folded siliceous granulites of the Moine Series, Ross of Mull.*

FIGURE 4 – *Quartz rods in the cores of folds. Each mass is elongated parallel to the axes of the folds. The outcrop is 2 metres high and shows the quartz rods in cross-section. Figure 6a shows similar quartz masses. Ben Hutig, Sutherland.*

FIGURE 5 – *Siliceous rock from Unst, Shetland, showing e of repeated deformation: a lineation, seen as a faint striation, been twisted during folding associated with the third metamor episode described in the text. The specimen is approximately 4 in length.*

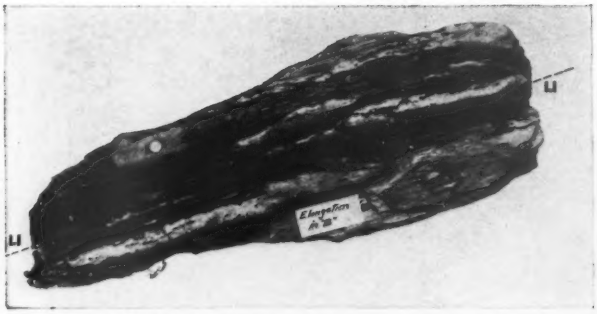
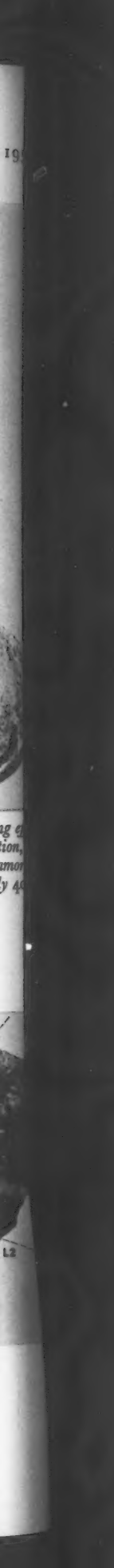


FIGURE 6 – (*a*) (*above*). *Elongated masses of quartz in a lineated rock. The structures are parallel to the local fold axis. The rock has been folded once. The specimen is 30 cm in length.* (*b*) *Here the rock has been folded twice. Quartz rods and lineations formed in an earlier period of folding (L1) run from bottom left to top right, and have been twisted in a later period of folding, during which the folds marked L2 were formed. The specimen is 25 cm in length.*



determined in south Harris and in Arendal, southern Norway.

THE RECRYSTALLIZATION OF METAMORPHIC ROCKS

The dating of crystalline rocks involved in two orogenies has been approached from a rather different angle by G. L. Davis, G. W. Wetherill, G. R. Tilton, and C. A. Hopson [9]. They investigated minerals from the Baltimore Gneiss, a rock group in the Appalachians whose age has been a matter of discussion. They found the zircon to be 1100 million years old, using the uranium : lead ratio, and the felspar microcline to be 1200 ± 200 million years old. Biotite gave ages of 310 million years from both the rubidium : strontium and the potassium : argon ratios. From these results they concluded that the Baltimore Gneiss had originally been formed in Pre-Cambrian times, about 1100 million years ago, and that it had been re-metamorphosed during the Palaeozoic earth movements and metamorphism about 300 million years ago, when the biotite formed. That different minerals of a single rock should have crystallized at such widely separated geological times may seem surprising. It appears to accord well, however, with the geological history of the Baltimore Gneiss, as reported by those who have investigated it in the field.

Evidence suggesting such an occurrence in Britain has been available since early this century, though no measurements of absolute age have yet been made on the material. Over fifty years ago, officers of the Geological Survey described [10] the occurrence of radiating clusters of the mineral hornblende in Lewisian rocks which had been involved in the later Caledonian movements, and demonstrated that the present form of the hornblende dated from Caledonian times. Recently it has been possible to carry this argument a stage further, and to show in which of several phases of Caledonian movement such hornblendes recrystallized. These hornblende-bearing gneisses are good examples of metamorphic rocks in which an early arrangement of minerals has been partially superseded by a new arrangement. Such rocks can be described as polymetamorphic: they are formed not only by the superposition of metamorphoses occurring in independent periods of mountain building, but also during the successive phases of a single mountain-building cycle. The mapping of sequences of mineral assemblages and, still more, the mapping of successions of geological structures, offers a way of establishing the metamorphic history of crystalline rocks produced during such successive phases. Investigations of this kind have been made for a long time, certainly since the start of this century, when B. N. Peach and others were interested in the orientation of minerals seen in crystalline rocks in the Scottish Highlands. In the last twenty-five years this work has received new impetus, from investigation of the micro-fabric of rocks and from observations made on deformed structures.

CRYSTAL ORIENTATIONS IN DEFORMED ROCKS

When new minerals develop in metamorphic rocks while these rocks are being deformed, the mineral grains are often oriented systematically in response to the deforming pressures (figure 2). A familiar example is provided by the manner in which the crystals of the platy minerals of a slate are arranged along the planes in which the slate cleaves. When it was discovered by B. Sander and W. Schmidt that approximately equidimensional minerals were also arranged systematically in metamorphic rocks, it was clear that the orientation was controlled in such instances by some internal property of the crystal lattice and not by the external form of the crystal grain. It has been found, for example, that in folded siliceous metamorphic rocks (figure 3) quartz particles may commonly be arranged so that their crystallographic 0001 axes fall in a plane normal to the axes of the visible folds. The reason for this is not yet clearly understood, but the existence of the phenomenon is now well established.

Quartz grains in siliceous rocks of the Moine Series in Scotland were found to be arranged in planes normal to a visible striation or lineation by F. C. Phillips [11], and subsequently he and other workers such as C. B. Crampton [12] have shown that many of the other rock-forming minerals in these rocks are systematically arranged. The fabric—that is, the arrangement of minerals—and the lineation also frequently bear a simple relationship to much larger structures, such as folds several kilometres in wavelength [13, 14]. At Scardroy in Ross-shire, for example, where the major folds run south-south-east, the most widely developed lineation (figure 6) follows this direction and the quartz grains have their axes arranged in a plane normal to this lineation. Similar relationships between microscopic fabric and large structures have now been established in many parts of the Scottish Highlands. These allow correlations to be made between mineral

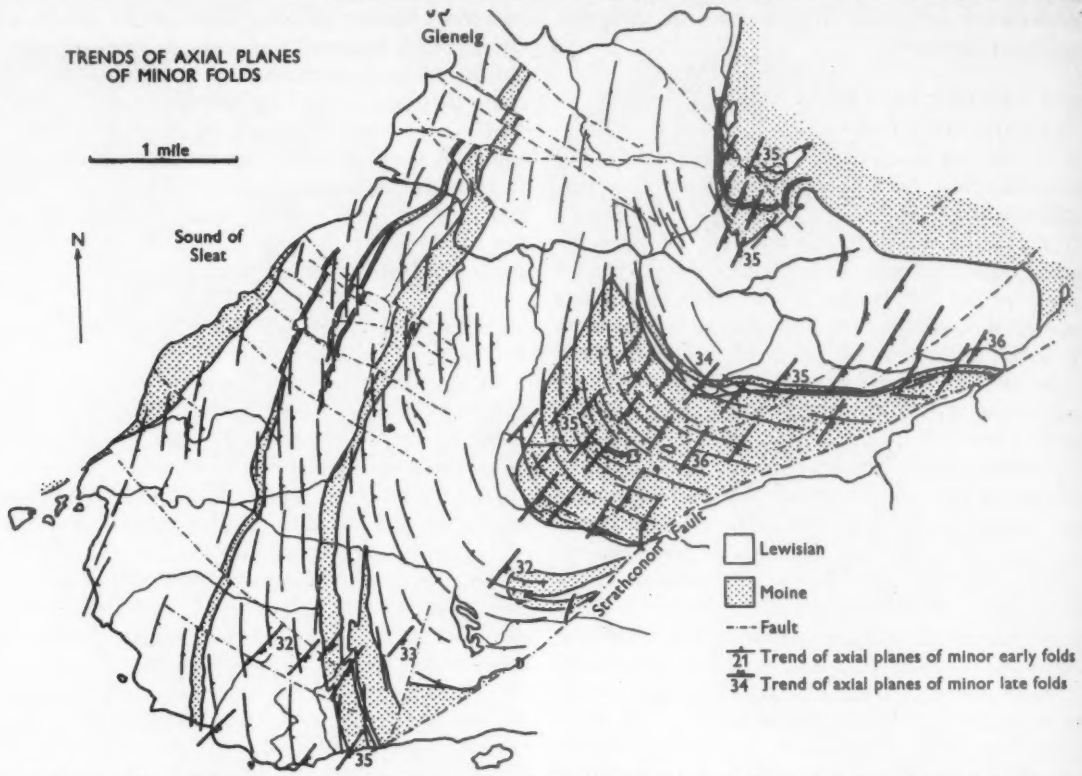


FIGURE 7 – *Map showing how planes of cleavage formed during one period of folding have been deformed during later movements which in turn produced further planes striking north-east.* (*After J. G. Ramsay* [16].) *Glenelg, Inverness-shire.* (*Figures 1 and 7 are reproduced by courtesy of the Geological Survey.*)

assemblages many kilometres apart, when it can be shown that both are associated with a single large structure that can be followed across the intervening ground. The most useful structures are the large folds, the smaller structures such as folds a few metres across, and the cleavage planes associated with them.

Recently, work on such structures has shown that at least three sets of movements affected the metamorphic rocks in parts of the Moines, and that one set is superposed on another. L. E. Weiss [15] gives a bibliography of recent papers on superposed structures. Successive movements are common in mountain building, and it has long been recognised that folds running in more than one direction and dating from more than one period were present in the Moine Series of Scotland. The new work breaks fresh ground in demonstrating how earlier structures are deformed by later ones, and how in turn the later structures are influenced by the earlier. Over much of central Ross-shire the rocks remain in the condition to which they were brought during the second of the three periods of folding which affected the rocks during the Caledonian orogeny. Locally, structures and minerals formed during the earliest period can be detected, and as these are traced into ground affected by the later movements, the folds, lineations, and cleavages formed in the first set of movements become distorted by the later structures which cut sharply across the earlier (figures 6, 7). When the microfabric is investigated, it becomes clear that the individual grains gradually take up new orientations related to the new structures. A third set of Caledonian structures is developed in much of the ground near the borders of Wester Ross and Inverness, and here, too, the superposition of new structures on old can be seen [14, 16, 17].

By linking metamorphism and structure one is thus able to distinguish three generations of minerals, to map out the domain of each on the ground, and to use the chronological succession so established to investigate new problems. One can, for example, find how metamorphism varied at any one place with the passage of time [16,17],

or how it varied across the region during an individual phase of folding. J. G. Ramsay showed [16] that, close to the north-west margin of the chain at Glenelg, there was little recrystallization in rocks affected by the third set of movements, whereas recrystallization was taking place in the Monar and Orrin districts [14, 18] at the time of these movements, and granite sheets were intruded along their axial planes after the folds had formed. In the two latter districts, which are some 25 km within the mountain belt, the conditions of metamorphism appear to have changed only very slightly during the movements, whereas near the edge of the chain the metamorphism was clearly waning as the third set of folds developed.

The island of Unst in Shetland clearly exemplifies repeated metamorphism accompanied by striking mineralogical changes [19]. Examination of the structures provides striking confirmation of the three-fold metamorphic sequence found by H. H. Read in the west of Unst. There is a strong lineation present in staurolite-kyanite-garnet gneisses formed in the first episode. Both this lineation and the crystallized quartz rods are twisted about new axes on the margin of the domain where a second episode can be detected. Where the new minerals such as chloritoid, characteristic of the second metamorphic episode, are well developed, the earlier structures have been destroyed and the new folds and lineations become dominant. Read recognized a third set of metamorphic minerals along a belt of intense deformation down the centre of Unst, and these also are marked by a characteristic set of structures (figure 5).

The successions of events discussed here suffer from several defects as potential geological time scales. There is the likelihood that either deformation or metamorphism may be diachronous and there is the uncertainty of the time interval between successive phases, which may themselves be prlonged. Nevertheless, the methods provide evidence concerning the relative time relations of deformation and metamorphism, and of intrusion where this has occurred. The methods can be applied to large areas of ground and provide a sequence which can be linked with age determinations based on the classical methods of stratigraphy, on palaeomagnetic studies, or on measurements made on radioactive minerals. The techniques are complementary and offer the prospect of extending the range of historical geology into regions where the classical methods fail when used alone.

This article has been mainly concerned with the author's work in Scotland, but a similar approach has been used in other countries. Thus for many years a vigorous school of structural geologists in Austria, led by B. Sander, has been studying how the metamorphism and deformation affected the way minerals are arranged in metamorphic rocks. The Norwegian geologist A. Kvale has investigated sequences of events determined in crystalline rocks in Norway which were deformed and metamorphosed during the Caledonian earth movements, and recently he has taken up similar problems in Switzerland in an area where crystalline gneisses that originally developed in an earlier episode of mountain building were deformed once more during the Alpine orogeny. E. Wenk has recently published the results of a prolonged investigation of small-scale structures in the Swiss Alps, and has shown how the study of such features folds a few metres across and the linear arrangement of minerals can be used to work out the historical geology of the crystalline rocks of the Alps.

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Bicentenary of the Royal Botanic Gardens, Kew

C. E. HUBBARD

The Royal Botanic Gardens, Kew, this year celebrate their bicentenary—two hundred years of almost continuous endeavour and advancement. During this time Kew's numerous and varied contributions to botanical science and to the welfare and prosperity of peoples in many lands, particularly those of the British Commonwealth, have gained it international renown.

It was in the year 1759 that the Princess Augusta, Dowager Princess of Wales, founded a botanic garden in the grounds at Kew. As a Royal Garden, however, it dates from 1730, when the Princess's husband Frederick, son of George II, obtained a long lease of Kew House (now demolished) and began laying out about 9 acres of the property. After his death in 1751 the Princess continued to live there and, being keenly interested in all kinds of plants, proceeded with the development of the Garden. In this work she received much help, encouragement, and advice from the Earl of Bute, a great friend of the royal family and an enthusiastic botanist.

There is little information available about the early formation and arrangement of the Garden, although it is known that William Aiton—who had been trained by the celebrated gardener and botanist Philip Miller at the Apothecaries' Garden, Chelsea—was engaged in 1759 to take charge of the laying-out and planting of the new botanic garden at Kew. The area selected for this garden was divided into two nearly equal parts. In the southern half were planted a collection of herbaceous plants arranged according to the Linnean system, a large selection of grasses, and special collections of British and alpine plants. The northern portion, separated from the southern by several hothouses and walls, was planted with trees and shrubs and called the arboretum. Many of these woody plants were recent introductions to Britain, but known to be hardy; a large number of them came in 1762 from the Duke of Argyll's garden at Whitton in Middlesex. Of these there still remain at Kew an ancient maidenhair tree (*Ginkgo biloba*), a false acacia (*Robinia pseudoacacia*), and a Turkey oak (*Quercus cerris*).

Under Bute's guidance, the Garden soon gained recognition as a scientific establishment, and the collections increased rapidly in both quantity and quality. Bute lived at Kew, and kept his botanical specimens and library in a separate building near Princess Augusta's Garden. It was perhaps here that John Hill, a noted botanist of the day, prepared his catalogue, *Hortus Kewensis*, of the 3400 species then cultivated in the Royal Garden —a work of 458 pages, published in 1768. It included 26 new species, mainly of North American origin, 20 of which were illustrated by excellent coloured plates in the second edition, issued in 1769. A manuscript catalogue of the trees and shrubs in the royal collection, prepared in 1773, shows that it then contained 791 species and varieties.

On the death of George II in 1760, Princess Augusta's son succeeded to the throne as George III and took over Richmond House, the residence of his grandfather, the grounds of which were adjacent to those of Kew House. When his mother died in 1772 he purchased the freehold of the latter property, but it was not until 1802 that the two gardens were united. From the joining of the grounds of these two houses the present use of the plural title, Royal Botanic Gardens, has been derived.

In 1771 or 1772 the young king became acquainted with Mr (later Sir) Joseph Banks, who had just returned from Captain Cook's voyage of discovery to the Pacific Ocean in the *Endeavour*, during which he had served as naturalist. He became the King's scientific adviser and, taking a keen interest in Kew, succeeded Bute as honorary director of the establishment. Under his guidance the Gardens soon became the principal European botanical institution devoted to the culture of plants, being famed for the great diversity and scientific value of their collections. Scarcely a voyage of discovery of any importance left the shores of Britain without one of Banks's botanists or plant-collectors from Kew, and he sent others on

special expeditions to many parts of the world to gather seeds and plants to add to the ever-increasing catalogue of Kew plants.

Three examples from the early records of Banks's introduction of plants may be mentioned here, but many other collectors gave similar valuable help in the interchange of economic and horticulturally important plants carried out at Kew, a service in which it is still actively engaged.

The first of Banks's plant-collectors, Francis Masson, a gardener at Kew, was sent to the Cape of Good Hope at the beginning of 1772, where during two and a half years he gathered a great profusion of new plants for the Royal Gardens; on some of his expeditions he was accompanied by Thunberg, a famous pupil of Linnaeus. He also visited the Canary and other North Atlantic islands as well as the West Indies before returning once again to the Cape for almost ten years. In paying tribute to Masson, Banks stated it was in great measure as a result of his endeavours that Kew attained its acknowledged superiority over similar establishments.

Another famous enterprise in which Banks and Kew were closely concerned was Captain William Bligh's voyage in the *Bounty* in 1787 to the South Seas to collect plants of the breadfruit for introduction to the West Indies. Bligh was accompanied by two Kew gardeners, David Nelson and William Brown. Although the expedition obtained large numbers of plants, the mutiny of the crew, in which Brown joined, led to the failure of the project. On a similar mission in the *Providence* in 1791, Bligh—accompanied once more by two Kew men, Christopher Smith and J. Wiles—was successful in safely conveying a cargo of young breadfruit trees to Jamaica and other West Indian islands, whence they were rapidly introduced throughout the region. Another economically valuable plant, the Otaheite sugar-cane, was introduced by Bligh's collectors at the same time. By 1819 this cane had become firmly established throughout the West Indies, and it is recorded that on Barbados the annual yield of sugar from it for the preceding five years averaged 12 565 tons. For at least a century this variety of sugar-cane was planted almost to the exclusion of any other in Barbados, but finally it became weakened by disease and its cultivation had to be abandoned.

Masson was the first of a long line of Kew men who during Banks's lifetime, and after his death in 1820, dispatched vast numbers of plants and seeds to the Gardens. James Bowie and Allan Cunningham were sent to Brazil in 1814, George Caley travelled to Australia in 1799, and William Kerr to China in 1803. In 1817 Cunningham was posted to New South Wales. As a result of his journeys there and in other parts of Australia he became internationally famous as a botanist and explorer. A continuous stream of new and rare plants, living and dried, was sent home by this remarkable young man. He travelled widely, far into the interior of New South Wales, crossed the Great Dividing Range in Queensland through the gap which now bears his name, and accompanied Captain King in the *Mermaid* on the surveys of the north and north-west coasts of Australia.

The names of some of the plant introductions of the Kew botanical collectors were incorporated in the *Hortus Kewensis* of William Aiton, published in 1789, in which about 5500 species are described. Others are listed in the second edition of this work by his son, who succeeded him as a superintendent of the Gardens in 1793. By then, 1810–13, the number of species grown had increased to 9800.

During the twenty-one years following Banks's death the Gardens suffered from a certain amount of neglect in their management, although the plants were maintained in a good state of cultivation by the gardening staff, especially as a result of the industry and enthusiasm of John Smith, who became Curator in 1841. The unsatisfactory condition of the Gardens was brought to the notice of the Government and led to the appointment in 1838 of a committee of inquiry consisting of a botanist, John Lindley, and two gardeners, Mr (later Sir) Joseph Paxton and Mr Wilson. As a result of their recommendations the control of the Gardens was transferred to the Commissioners of Woods and Forests in 1840. Dr (later Sir) William Jackson Hooker, Professor of Botany in the University of Glasgow, was nominated their first official Director in April 1841.

There were then about 15 acres of grounds, crowded with trees, shrubs, and herbaceous plants, but there was no herbarium, museum, or laboratory. The greenhouses were in a bad state of repair, and both these and the Gardens generally were totally inadequate for the rich collections already there, quite apart from the plants and seeds which constantly arrived from every quarter of the globe. However, before Hooker's death in 1865, not only had the huge Palm and Temperate houses and the first Museum of Economic Botany been built and a magnificent herbarium and library established in Hunter House, but the layout of the grounds had been reorganized, and they were extended nearly to their

present size and judiciously planted with a fine selection of hardy trees, shrubs, and herbs.

Hooker edited various scientific periodicals, such as the 'Botanical Magazine', the *Icones Plantarum*, and his own 'Journal of Botany', to all of which he contributed numerous articles; the first two continue to be prepared at Kew almost 120 years later. It was he who planned and initiated the extensive series of floras of the countries of what is now the British Commonwealth, in the elaboration of which Kew continues to provide botanists everywhere with taxonomic works for the identification of plants. In these and many other ways he laid the foundation for the future development of Kew as an international centre for botanical research. He attracted and encouraged botanists of all nations by a very extensive correspondence, by the provision of excellent facilities for study, by the exchange of living and preserved plant-material, and by organizing surveying and collecting expeditions to undeveloped regions.

Under the wise direction of Dr (later Sir) Joseph Dalton Hooker, who succeeded his father in 1865, the Gardens continued to prosper, improvements and additions being made to all parts of them. He collaborated with his friend, George Bentham, in the preparation of the *Genera Plantarum*, a descriptive account in Latin of all the genera of Phanerogams and Gymnosperms. This is a classical work on their taxonomy, and it has provided an excellent basis for the arrangement of many floras and plant-lists, both for the botanical collections at Kew and for other Commonwealth and foreign herbaria. His own contributions to botany, especially in the fields of description, classification, and phytogeography, were enormous. He edited and wrote much of the 'Flora of British India', besides floras of New Zealand, Tasmania, and the Antarctic regions. The Jodrell Laboratory for research in anatomy and physiology was built in 1876, and a new wing was added to the Herbarium in 1877 to house the huge collections of dried specimens received at Kew. Before Sir Joseph Hooker retired in 1885, Kew had become the foremost international centre for botanical research, particularly in systematic botany.

The Royal Botanic Gardens, Kew, as we know them today, are very largely the creation of the two Hookers, both endowed with tremendous energy, remarkable foresight, and ability. They were first-class administrators and organizers and, above all, botanists of the highest quality. Subsequent Directors continued the policy of their distinguished predecessors in fostering a close association with botanists and botanical establishments in the countries of the British Commonwealth, especially in matters concerning taxonomic and economic botany. The 'Kew Bulletin' began publication in 1887 to record the results of researches carried out at Kew; with its additional series and supplements this now comprises eighty volumes.

The main functions of the Gardens, as envisaged about the time of their presentation to the nation by Queen Victoria in 1841, were scientific work; the cultivation of plants from all parts of the world; the instruction of the public; the propagation of useful plants for distribution to various overseas territories of the British Commonwealth; and, finally, furnishing the Government with general information on botanical subjects. At the present day, with these purposes in mind, the Gardens are divided into the following five departments:

1. Herbarium and Library, a research institution primarily for the accurate identification and classification of plants.
2. Jodrell Laboratory, a research department for the study of the anatomy and physiology of plants.
3. Museums of Economic Botany, for the instruction of the public in the uses of plants, the supply of information in the field of applied botany, and the economic exploitation of plants.
4. The living collections in the Gardens, in which are cultivated more than 25 000 species of flowering plants and ferns and from which plants and seeds are distributed to similar establishments both at home and overseas.
5. The National Pinetum, Bedgebury, Kent, containing the living collection of hardy species of the *Coniferae*.

The Herbarium and Library were founded in 1853, when accommodation for specimens and books was provided in Hunter (Hanover) House, previously the residence of the Duchess of Cumberland and her husband. The collections forming the basis of this department were those of William Arnold Bromfield; the extremely valuable herbarium and library of George Bentham, given in 1854; and the huge collections of Sir William Hooker which had been on loan to Kew since 1841 and were purchased in 1866. The joint herbaria of Bentham and Hooker, together with other important gifts and purchases of botanical collections,

provided the establishment with an excellent foundation for the floristic researches planned by Sir William.

KEW TODAY

The Herbarium continues to increase as the vegetation of all regions is studied in greater detail, the additions over the past ten years averaging about 60 000 annually. The specimens are housed in three wings, the total collection comprising over six and a half million sheets of mounted material of all groups of plants; it includes a fairly high representation of the known species from most parts of the world. The dried material is supplemented by more than 15 000 bottles of flowers and fruits in liquid preservative and by large numbers of fruits and seeds in boxes. The Herbarium is exceptionally rich in original (type) and authentically named specimens. Because of these, and of the historic material which formed the basis of the earlier Kew floras, the assistance of Kew is continually being sought by botanists overseas in the revision of existing works and in the writing of new floras.

The results of research carried out in the Herbarium by members of the staff and by visiting workers, many of whom have spent long periods at Kew, have been published as papers in a wide range of scientific periodicals or as separate works. In 1863, Sir William Hooker put forward his proposals for a series of floras of parts of the British Commonwealth, and the preparation of these has claimed the attention of Kew botanists and visiting workers for about a hundred years. Starting with the Flora of the British West Indian Islands between 1859 and 1864, the series has included accounts of the plants of Australia, Tasmania, New Zealand, the Fiji Islands, the Malay Peninsula, Hong Kong, India and Ceylon, Mauritius and the Seychelles, tropical Africa, South Africa, and of smaller regions and islands, mainly in the Old World. Floras now in preparation in the Herbarium include the second edition of the 'Flora of West Tropical Africa', a 'Flora of Tropical East Africa', and floras of Cyprus and of Iraq.

The abstracting of new generic and specific names of flowering plants from botanical literature, for listing with their place of publication and country of origin in the *Index Kewensis* is still being carried out. This indispensable service for botanists, horticulturists, and others working with plants was commenced at the suggestion of, and financed in the first place by, Charles Darwin. It comprises 14 large quarto volumes. A supplement is issued now for each period of five years; that for the quinquennium 1951–55 contained about 20 500 names. The original two volumes were published in 1895 and the 12 supplements include about 830 000 entries of generic and specific names.

The *Index Londinensis*, listing the published illustrations of flowering plants and ferns, the compilation of which was undertaken at Kew and financed by the Royal Horticultural Society, consists of four volumes and two supplements, the whole covering the years 1753–1935. This important work is not only of great value as an index to plant portraits but also as a guide to the literature on a particular plant, as many such studies include an illustration.

Botanical art is not neglected at Kew. Since 1841 the 'Botanical Magazine' has been edited and mainly prepared there, its illustrations in colour of individual plants now totalling about 10 000 plates and filling 172 volumes. The 36 volumes of the *Icones Plantarum* contain nearly 3600 illustrations in black and white and descriptions of new or rare plants in the Herbarium.

The Library is thought to be the largest and the most comprehensive collection of botanical works in existence. It comprises over 55 000 bound volumes, about 80 000 separates and reprints, a collection of about 150 000 paintings, drawings, and photographs, and approximately 6500 maps. The number of periodicals taken is 700.

The Jodrell Laboratory, which was built and equipped in 1876 at the expense of T. J. Phillips Jodrell to provide facilities for research in plant anatomy and plant physiology, is still a comparatively small building. Nevertheless, many famous botanists have carried out fundamental anatomical, biochemical, mycological, and physiological investigations within its walls. The microscopical identification of timbers, fibres, and parts of plants used for medicinal and other purposes has been one of its chief services to scientific botany. In this connection the present Keeper of the Laboratory, Dr C. R. Metcalfe, collaborated with L. Chalk in the preparation of a new work of 1500 pages on the 'Anatomy of the Dicotyledons', published in 1950. It is based on a review of the literature on this subject published since the appearance of Solereder's 'Systematic Anatomy of the Dicotyledons' in 1908, and on the results of original observations made on a vast collection of microscopic preparations of the tissues of stems, leaves, and roots, commenced in 1930 and now numbering more than 20 000 slides. The staff,

with the assistance of collaborators in other institutions, is now engaged on the preparation of a companion study of the anatomy of the Monocotyledons, of which the first volume, relating to the grasses, is now being printed. The Laboratory provides a unique centre for investigation of botanical problems requiring the co-operation of taxonomists, anatomists, cytologists, and physiologists, since in no other institution in the world is such a wealth of plant material available for study.

The three Museums of Economic Botany contain vast collections of plant products of all kinds used in identification, for research, and for display purposes. Two are devoted to the Dicotyledons and Monocotyledons, and one to the collection of timbers and objects made of wood. The staff of this department, being concerned mainly with the economic exploitation of plants, has to answer a wide range of inquiries relating to their uses, and in so doing has investigated in recent years vegetable gums and resins, tanning materials, fibres, medicinal plants, and nuts and seeds in great variety.

Kew has played a most important part in the introduction of new plants of economic value to many countries of the Commonwealth, two well-known examples being the supply of Para Rubber to Malaya and Ceylon and of species of *Cinchona* (the source of quinine) to India. Kew has sent out a great variety of useful plants since its early days. At first a wide range of fruits, nuts, vegetables, and ornamental plants were sent to newly developed areas for the use of the settlers and, later, a variety of other economic plants such as forest trees, medicinal plants, and others yielding fibres, resins, gums, and oils, as well as cereals and crop plants of many kinds. Kew continues to serve as a quarantine station where plants in transit from one part of the Commonwealth to another may be inspected and held for some time to prevent the spread of diseases and pests. For example, those of cacao, banana, cotton, and rubber have passed through Kew before transmission to Ghana, Nigeria, Malaya, Fiji, Trinidad, and Ceylon. An active exchange of living plants and seeds has been maintained since Banks's time with botanical, horticultural, and agricultural institutions both at home and overseas. Many of the ornamental plants of North and South America, eastern Asia, Australia, New Zealand, and South Africa have been propagated at Kew and distributed through European and American botanical establishments to enrich private gardens in many lands.

In addition to its other services the Royal Botanic Gardens have from the first provided excellent opportunities for those seeking to improve their knowledge of botany and horticulture. Many members of its junior staff, benefiting from the extensive practical and theoretical training received in the Gardens, have gone to all parts of the Commonwealth as curators of botanic gardens and agricultural experiment stations, or have taken charge of plantations, nurseries, parks, and gardens. At the present time Kew-trained men occupy important posts in 54 countries. The largest number overseas are in the United States; but many are to be found in Canada, New Zealand, South Africa, and Australia. From time to time gardeners from Kew have travelled widely in the Himalayas, western China, and North and South America, and in so doing have made valuable collections of seeds for the Gardens and of dried specimens for the Herbarium.

From the time of Sir William Hooker, Kew botanists have been sent on expeditions and missions of investigation and exploration or have joined surveying parties, to study the vegetation of the regions concerned and to preserve plants for the Herbarium. Since 1920 extensive collections have been made in this way in British Guiana, West Indies, Ceylon, Indonesia, Australia, and most Commonwealth countries in Africa.

In this age of specialization it is no longer possible for those studying plant life to cover the entire field of pure and applied botany, except in a very general manner. Thus Kew's investigations are concerned mainly with the taxonomy and anatomy of plants and their cultivation and economic uses. They might be extended with advantage, however, to include most branches of plant science, and so make the fullest use of the unrivalled collections.

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Book reviews

PHILOSOPHY AND ASTRONOMY

The Individual and the Universe, *by A. C. B. Lovell. Pp. v+111. Oxford University Press, London.* 1959. 10*s.* 6*d. net.*

The technical developments in radio astronomy and the launching of earth satellites have within recent years brought about a revolution in astronomical observations. The large radio telescopes of today can probe the universe to depths beyond those accessible to the Palomar 200 in. telescope. These developments may have suggested to Professor Lovell 'The Individual and the Universe' as the subject of the Reith Lectures broadcast by him in 1958 and published in this book.

In the course of the lectures the progressive change in man's outlook on the universe is outlined, from the view, which prevailed for many centuries, that the Earth was the centre of the universe to the present view. The possibility is discussed of a decisive observational test between the two rival cosmologies, the one supposing that there was an initial creation of a primeval atom, and the other assuming that the universe is in a steady state, with the necessary consequence of the continuous creation of matter.

Large radio telescopes are expensive to build and operate. This raises the question of state support for astronomy, which is discussed at some length. Such support was given in the United Kingdom long before it was given in the United States, but the great advance in observational astronomy in the United States in fact followed the many private benefactions for the construction of large telescopes. The rapid developments in astronomy in the Soviet Union, on the other hand, have been brought about by the considerable funds provided by the Academy of Sciences, a state organization.

Various developments in astronomy are now linked with the requirements of the armed services. The basis of the present economic and cultural strength of the Great Powers can be traced back, as Professor Lovell points out, to fundamental scientific investigations carried out in the abstract, without thought of direct practical developments. But now, in astronomy as in some other branches of science, the pursuit of good and evil are linked. This is a situation that cannot be regarded without some apprehension for the future; restraints on freedom of investigation and publication may reduce the effectiveness of research.

H. SPENCER JONES

QUANTUM MECHANICS

Quantum Mechanics. Non-Relativistic Theory, *by L. D. Landau and E. M. Lifshitz (translated from the Russian by J. B. Sykes and J. S. Bell). Pp. xii+515. Pergamon Press Ltd, London.* 1958. 80*s. net.*

This is volume III of the authors' course in theoretical physics. The contents comprise non-relativistic quantum mechanics and some of its applications. More particularly, the topics discussed include basic principles, motion in a central field, perturbation theory, electron spin, theory of atoms, di- and polyatomic molecules, theory of symmetry, and theory of elastic and inelastic collisions. In the authors' words, 'We have tried to deal as fully as possible with those topics that are included—we attempt to discuss general topics in such a way that the physical significance of the theory is exhibited as clearly as possible and then to build up the mathematical formalism. In doing so we do not aim at mathematical rigour of exposition which in theoretical physics often amounts to self-deception.'

I consider this as perhaps the best textbook available on non-relativistic quantum theory. The comparison is of course not with the works of Dirac and Pauli. The present volume attempts to teach more by example than precept. There seems, at present, a phase in textbook writing in the Soviet Union (at least among most texts so far translated) which combines comprehensiveness as well as depth with admirable readability. There is a sense of artistic delight in detail, and this book is fully a part of this growing tradition. Someone has discovered the happy secret which persuades the best men in science to write textbooks.

A. SALAM

ELEMENTARY PARTICLES

Progress in Elementary Particle and Cosmic Ray Physics, *Vol. IV, edited by J. G. Wilson and S. A. Wouthuysen. Pp. xii+470. North-Holland Publishing Co., Amsterdam.* 1958. 45 *guilders.*

This is the fourth volume in the well-known North-Holland series on elementary particles and cosmic rays. The earlier volumes of the series confined themselves to elementary particle interactions as observed in cosmic rays. With the present volume a departure has been made to include also data from the great accelerating machines in the United States. This change of emphasis reflects itself in a chapter on κ-meson production (W. D. Walker) and a chapter on theoretical ideas concerning the phenomena of 'strange' particles (B. D'Espagnat and J. Prentki). The remaining three chapters, forming the bulk of the book, deal with interaction of μ-mesons with matter (G. N. Fowler and A. W. Wolfendale), the composition and time variation of primary cosmic radiation (S. F. Singer) and the origin of cosmic radiation (V. L. Ginzburg). The difference in treatment between the first two and the remaining chapters is perhaps characteristic of the preliminary—and in the case of theoretical ideas mainly speculative—nature of the work in elementary particle physics as contrasted with the stage of 'maturity' reached in cosmic-ray physics. If only for the sake of the last three chapters, the book is invaluable for the workers in this field.

A. SALAM

NUCLEAR PHYSICS

Nuclear Structure, *by L. Eisenbud and E. P. Wigner. Pp. viii+128. Princeton University Press, Princeton; Oxford University Press, London.* 1958. 25*s. net.*

In the post-war years a great deal of effort in both experimental and theoretical physics has been devoted to the study of the atomic nucleus. Although we still do not know the detailed form of the interaction between nucleons, considerable progress has been made in interpreting the wide range of experimental data concerning complex nuclei. This is still largely carried out in terms of simple models such as the shell model or the alpha-particle model. None of these can represent more than a certain number of observed facts about nuclei, but the success of some of them, particularly the shell model, has been greater than expected. Nuclear physics is still in the Keplerian phase where order is being sought amid the great wealth of experimental data. The Newtonian phase will have commenced when we fully understand why some of the models are so successful.

The great merit of this book is its conciseness. At no time is the reader lost in a mass of detail, and yet sufficient data are given to explain the need for

the introduction of a particular interpretative mode of approach and to discuss its successes and limitations. The authors are to be congratulated on this excellent contribution to the understanding of the subject. This book will not only be of the greatest value to students beginning serious study of nuclear physics, but will be of absorbing interest to experienced workers in the field who have not had the opportunity of sitting back and calmly reviewing the situation reached. The fact that a book of this kind can be written at all is strong evidence that a considerable degree of order already prevails.

The first four chapters are concerned with summarizing nuclear properties, being on, respectively, general features of nuclei, systematics of stable nuclei, properties of nuclear states, and survey of nuclear reactions. After a brief account of the interaction between nucleons in chapter 5, the next three chapters are concerned with nuclear models—the uniform model in chapter 6, independent particle models in chapter 7, and many-particle models in chapter 8. Chapters 9 and 10 deal with nuclear reactions, the former being concerned with close collisions and the latter with surface reaction. The final two chapters discuss interaction with electron-neutrino fields and electromagnetic transitions in nuclei. A very useful list of references occupies the last ten pages. H. S. W. MASSEY

CHEMICAL KINETICS

Some Problems of Chemical Kinetics and Reactivity, *Vol. I, by N. N. Semenov. Translated from the Russian by J. E. S. Bradley. Pp. x+305. Pergamon Press Ltd, London.* 1958. 50*s. net.*

Academician Semenov is world famous for his contributions to the theory of chain reactions. The subject itself has spread over the world by a branching chain, and there is a vast amount of experimental data on chemical systems of the most diverse kinds. In this book the author seeks in some measure to systematize this great accumulation.

He tabulates activation energies, heats of reaction, bond energies, relative reactivities of different radicals, and so on, and wherever possible relates them, sometimes by expressions of a semi-empirical quantitative nature.

Free radical reactions are classified, and methods of finding the constants of individual steps are discussed. Where possible, the principles which allow the absolute rate of each step to be predicted in order of magnitude are considered.

Methods of initiation and termination are analysed in great detail, heterogeneous initiation of chains by free valency sites on walls of containing vessels being discussed in an interesting and suggestive way. There is a description of some recent Russian work which, if not wholly convincing, is ingenious and thought-provoking.

The book is written by a master hand. It makes clear the personal view of its distinguished author on the major disputed topics (and sometimes this view does not altogether commend itself to the reviewer): it always provides a wide survey of the literature, and on controversial matters both sides of the question are usually well stated. C. N. HINSHELWOOD

INORGANIC CHEMISTRY

Nouveau traité de chimie minérale, *Vols. III and IV, edited by P. Pascal. Vol. III, pp. xii+838. Vol. IV, pp. xxxix+973. Masson et Cie., Paris.* 1957 and 1958. *Vol. III, paper covers, fcs.* 6000; *bound, fcs.* 6900 *net. Vol. IV, paper covers, fcs.* 7500; *bound, fcs.* 8500.

This new treatise on inorganic chemistry when completed will consist of twenty volumes. The third and fourth volumes have recently appeared and constitute a valuable part of the new work. The third volume is concerned with the elements rubidium, caesium, francium, copper, silver, and gold, while the fourth volume is devoted to an account of the sub-group beryllium, magnesium, calcium, strontium, barium, and radium. The various authors follow a general pattern in the treatment of this subject. A short history of the element, and an account of its occurrence in nature and its isolation, are given concisely, and then follows a detailed account of its more important physical and chemical properties. Mention is made of the analytical chemistry of the element, with a section on its main uses. Finally, a wealth of information is given about interesting and important compounds which the element forms with a wide range of other elements. Some idea of the comprehensive nature of the information included can be seen from the fact that in the third volume, 6997 references are given to original papers relevant to items mentioned in the text. In the fourth volume the number of references is 8873. When an element forms derivatives involving the use of organic substances, such organometallic compounds are specially dealt with. It is appropriate that the account of the element francium should be written by Marguerite Perey. The literature is full of early claims and counterclaims to the isolation of element 87, but until the work of Marguerite Perey in 1946 none of the claims were substantiated to the general satisfaction of critical reviewers. The name agreed by the International Union of Chemistry is francium and the symbol Fr. Incidentally, the references to this element do not go beyond 1st April 1956. The various authors who contribute to these two volumes are to be congratulated on an exposition orderly, lucid, and detailed, and the publishers must be complimented on the production of two very handsome volumes. One cannot but regret that the cost of the whole work will place it beyond the means of many libraries and institutions where it might be most useful. W. WARDLAW

ROCKETS AND SATELLITES

Rockets and Satellites, *edited by L. V. Berkner. Pp. xx+508. Pergamon Press Ltd, London.* 1958. £8 *net.*

Before the International Geophysical Year more than 100 rockets were launched into the upper atmosphere in the conduct of scientific research. The I.G.Y. was distinguished from earlier international co-operations in many ways, not the least being the extensive use of these new techniques—indeed, it will always be remembered most of all for the introduction and phenomenally rapid development of the use of artificial satellites. There is no single source to which an inquirer may turn in his search for data on these aspects of research, but in this book, which is Volume IV of the Annals of the I.G.Y., there is a miscellaneous collection of information on the research programmes, instrumentation, and vehicles of many nations. A very large part is taken up with descriptions of the huge research effort of the United States. It is a pity that the comparable effort of the Soviet Union has not been reported in detail. This, however, is not the fault of the editor. Presentation is far from uniform, for the book is simply a compilation, and it is sometimes repetitive. Nevertheless it remains a valuable and in many ways a comprehensive work of reference. R. L. F. BOYD

THE UPPER ATMOSPHERE

The Upper Atmosphere, *by H. S. W. Massey and R. L. F. Boyd. Pp. xii+333. Hutchinson & Co. Ltd, London.* 1958. 63*s. net.*

This book compresses into a little over 300 pages a readable and accurate account of our present knowledge of the phenomena taking place in the upper atmosphere, that is, at heights above about 30 miles. It begins with an account of 'The Relevant Physics' for the benefit of the non-scientist and, after a short general chapter on 'The Atmosphere', describes the techniques employing balloons and rockets for exploring the upper air. The next chapter describes the methods of measuring the temperature of the upper air by reflected sound waves and the ionization of the upper air by reflected radio waves, while chapters 6 and 8 describe the variations of the Earth's magnetic field and of the ionosphere under 'quiet' conditions. Chapter 9 gives an account of the disturbances which may occur on the Sun and the effects of these on the subjects of chapters 6 and 8. Chapter 7 brings together accounts of the luminous phenomena in the atmosphere, the air glow, the closely associated twilight flash, the aurora, and artificial glows produced by the injection of either sodium vapour or nitric oxide into the upper atmosphere. The book ends with a very good discussion of meteors, cosmic rays, and artificial satellites. Both the general and the scientific reader will find this an interesting and accurate account of the subject.

G. M. M. DOBSON

METEOROLOGY

The Green Flash and Other Low Sun Phenomena (*second edition*), *by D. J. K. O'Connell. Pp.* 192. *North-Holland Publishing Co., Amsterdam; Interscience Publishers Inc., New York.* 1958. 45*s. net.*

In this book on sunrise and sunset optical effects, pride of place is given to the green flash, perhaps the most striking of all atmospheric optical phenomena. Historical observations and hypotheses are described and a remarkably large bibliography on the effect is included.

There has been for some forty years no reasonable doubt that the green flash is a real physical effect which is to be explained in terms of differential wavelength refraction and absorption of the sun's light. The chief remaining doubt is the precise meteorological conditions which favour the appearance of the effect. Its notorious capriciousness suggests the need for atmospheric super-refraction (as when an air stream is cooled from below); the suggestion is strongly supported by the radiosonde temperature data quoted in the book but it is not supported to a significant degree by the measure of refraction afforded by a comparison of actual and theoretical sunset times on occasions of the green flash. It is rather disappointing that there is only scanty discussion of this aspect of the phenomenon.

The book is chiefly remarkable for its excellent photographs (colour, and black and white) of the green flash and other effects, taken at the Vatican Observatory by means of a telescope fitted with a camera. D. H. McINTOSH

ETHNOLOGY

Ciba Foundation Symposium on Medical Biology and Etruscan Origins, *edited by G. E. W. Wolstenholme and C. M. O'Connor. Pp. xii+255. J. & A. Churchill Ltd, London.* 1959. 45*s. net.*

This novel symposium, conceived by a biochemist and a classicist respectively of the University of Cambridge, was effectively summoned into existence by the Director of the Ciba Foundation, who brought together geneticists and physical anthropologists on the one hand, and archaeologists and historians on the other, and suggested that the biologists should help the humanists to settle, if possible, the long-disputed problem of the origin of the Etruscans. It is easy to collect conflicting statements about almost everything Etruscan, and in regard to central Italy we have not enough reliable data to allow us to draw either positive or negative conclusions about the existence of differences in blood group distribution which could eventually be related to the ethnic influence of the Etruscans. But the book is replete with interest, and should appeal to many in different disciplines. The members of the Symposium, aware of the value of studies on the frequency of distribution of blood groups for the understanding of important—and so far insufficiently investigated—points in common between the different ethnic groups, addressed a resolution to the National Committee for the Study of Blood Groups in Italy. Congratulations should rightly go to the Director for the successful establishment of a new technique. K. J. FRANKLIN

YEASTS

The Chemistry and Biology of Yeasts, *edited by A. H. Cook. Pp. xii+763. Academic Press Inc., New York; Academic Books Ltd, London.* 1958. $22.

A definite need existed for a book on the chemistry and biology of yeasts, and this volume will be welcomed eagerly by all interested in the subject. To encompass the ever-expanding universe of our recorded knowledge on yeast within the covers of one volume has been no light task, and the authors and editor deserve much credit for the manner in which this has been accomplished.

In this book will be found much well presented information on yeasts that has not been assembled elsewhere. The information does not always appear where it might be expected, and the index reveals that only two of the references to respiration are given in the chapter entitled 'Fermentation and Respiration'. On the other hand, careful editing has obviously prevented much overlapping of subject matter in different chapters. Unfortunately, in a book where the various chapters have been entrusted to different authors it is difficult to present the yeast cell as one co-ordinated system and to portray the various frontiers of our advancing knowledge as a connected whole.

The book is well produced and can be strongly recommended. It should be read by all concerned with yeast, and many will want to keep it close at hand. A. K. MILLS

ZOOLOGY

Anatomie de *Latimeria chalumnae. Vol. I,* Squelette et muscles, *by J. Millot and J. Anthony. Pp.* 122. *Centre National de la Recherche Scientifique, Paris.* 1958. *Fcs.* 9800.

In this sumptuous volume are summarized the results of Professor Millot's and Dr Anthony's careful investigations over a period of five years on the skeleton and muscles of *Latimeria* (coelacanth). The first volume of their fully detailed descriptions of the internal anatomy of these astonishing fishes has been devoted to the skeleton and musculature in view of the major importance in palaeontology of skeletal structures and the possibilities they offer of fruitful comparisons with extinct forms. Palaeontologists will indeed be grateful for this consideration, and they would scarcely be human if their gratitude were not tinged with a little envy at the

opportunities afforded by this marvellous material. Ten specimens of *Latimeria* in good condition, seven males and three females, have been available to the authors.

The outstanding results have already been announced in papers by Professor Millot and his colleagues, but here are the details so necessary for the palaeontologist to compare the living fish with his all too fragmentary material. The authors make valuable comparisons with the extinct forms and provide some salutary lessons in regard to the interpretation of fossil material—as, for example, in the lack of correlation between the enormous cranial cavity and the diminutive brain. E. I. WHITE

PROTECTION FROM RADIATION

Radiation Protection, *by C. B. Braestrup and H. O. Wyckoff. Pp. xix+361. Charles C. Thomas, Springfield, U.S.A.; Blackwell Scientific Publications, Oxford.* 1958. 80*s. net.*

This book presents a balanced picture of the hazards of radiation, but most of the protective measures discussed are in the medical field. This emphasis should be borne in mind by those seeking a guide to the more general aspects of protection.

Fluoroscopy comes in for some much-needed criticism as one of the most dangerous techniques, on account of the large total doses which may be given to both patient and operator.

Most of the discussion on shielding relates to the structure of buildings and, while this is important, there could well have been more attention paid to recent developments in X-ray machines directed towards restricting the radiation to the useful beam. The references are generally well chosen, but since they date up to the middle of 1958 they might have included the above topic. The protection of specific organs in the patient by individual shields is covered rather briefly.

In the section on luminizing operations, polonium is grouped with radium as a gamma-ray emitter. This is misleading, because polonium emits one gamma-ray to about every hundred thousand alpha-particles and so is considered to be a pure alpha-emitter for most practical purposes.

The book is well written and can be recommended as a guide to the subject, especially for radiographers. The last appendix, on cases of real and imaginary radiation injury, leaves the reader firmly on his feet. S. JEFFERSON

NUCLEAR EXPLOSIONS

Nuclear Explosions and their Effects (*revised and enlarged*), *foreword by Jawaharlal Nehru. Pp.* 276. *The Publications Division, Ministry of Information and Broadcasting, Government of India, Delhi.* 1958. 25*s. net.*

Essentially this book is an appreciation of biological hazards. The first four chapters, covering some 60 pages, outline the history, physical principles, and general effects of nuclear weapons. The next three chapters, on the biological effects, occupy over 200 pages.

The first edition appeared in 1956 and was a useful supplement to reports of the Medical Research Council (U.K.) and Academy of Sciences (U.S.A.) on biological hazards from all forms of ionizing radiation, whether produced for military or civil purposes.

This, the second edition, 'in its discussion of the hazards of nuclear explosions . . . goes very much further than the first edition, but the broad conclusions remain substantially the same', according to D. S. Kothari in an editor's preface. It appears at the same time as the recent report of the United Nations Scientific Committee on the Effects of Atomic Radiation and of necessity must be compared with this.

There can be no doubt that in war nuclear weapons could have horrifyingly lethal, dynamic, thermal, and radiological effects. What is contentious is the quantitative biological effect from the testing of such weapons in peacetime. The U.N.O. Committee accepted that there would be genetic consequences but rated them small compared with those of medical radiology: it treated potential damage to the individual (somatic effect) in two ways, the more pessimistic fundamentally comparable with the genetic and without a threshold, the more optimistic with a threshold which could scarcely be exceeded except in war or accident. Its report therefore gives the impression of being judicial. The Indian authors of this work give extreme weight to the theory that delayed somatic effects have no threshold for radiation dose and are uncorrelated with dose-rate. For example, page 199, 'the trend of present evidence favours the view that leukaemia is caused by mutations in (somatic) cells in the blood forming organs'—a statement which the reviewer and most investigators in the cancer field will strongly contest. Thus one is left with the feeling that the book advocates one point of view. J. F. LOUTIT

HAEMATOLOGY

British Medical Bulletin, *Vol. XV, No. 1.* Symposium on Haematology. *Pp.* 88. *The British Council, London.* 1959. 20*s. net.*

It is a fortunate coincidence that in this year 1959, when the European Society of Haematology is to meet in London, the first number of the British Medical Bulletin should be devoted to haematology. The first three papers deal with the absorption of iron and vitamin B_{12} and the role of folic acid in anaemia. With both iron and vitamin B_{12} the advance made possible by radioactive isotopes has now been consolidated, but although much is known about the part played by folic acid in biochemical reactions, methods for determining the folic acid status of the intact organism are still unsatisfactory. A second group of papers deals with haemoglobin. Many different varieties of haemoglobin have been discovered in the last decade. New light has been thrown on the balance between genetic and environmental factors in human populations, and the chemical nature of the defect in haemoglobin produced by the mutant gene has been determined. Other papers are concerned with haemolysis and the haemolytic anaemias—where the nicest bit of tidying up in clinical haematology since the war has taken place—the cytology of the blood cells and leukaemia. The high standard of editing of the articles deserves a special mention. L. J. WITTS

WAVEGUIDES

Proceedings of the Symposium on Electronic Waveguides, New York, April 1958, *edited by J. Fox. Pp. xix+418. Interscience Publishers Inc, New York; Interscience Publishers Ltd, London.* 1958. 40*s. net.*

The title of this symposium is an intriguing one in that, although the subjects of electronics and of waveguides are now both widely studied, they are not normally associated. The implications are, however, made clear in the foreword by Dr Weber, the President of Brooklyn Polytechnic, where the symposium was held. There are now many situations in which electromagnetic waves and electron beams interact, examples being the many varieties of microwave amplifiers and oscillators, and the propagation of radio waves in the ionosphere. The theoretical background of such diverse

problems stems from Maxwell's equations and the electrodynamical equations. In this volume twenty-six papers by the leading workers in this field have been collected and provide a very useful summary of the present state of development of this very important subject. The emphasis throughout is on basic principles, and although particular microwave devices are discussed, they are brought in primarily to illustrate the principles.

The book will be of most immediate value to those concerned with the design of microwave valves, and such readers will appreciate the speed with which the book has been published. A number of the articles have a more general interest, and that by Dr Kompfner on the new amplifiers and oscillators based on solid-state quantum effects and on the use of variable-reactance elements provides a masterly introduction to this subject. The general theorems on the interaction between electromagnetic waves and electron beams will undoubtedly also find applications in the field of magneto-hydrodynamics, which is now of great importance in the current work on fusion. J. BROWN

PLANT PATHOLOGY

Le Malattie delle Piante. *Part I*, Malattie da virus e da parassiti vegetali, *by J. Ceruti Scurti. Pp. viii+390. Loescher, Turin.* 1958. *Lire* 2500.

The book sets out to provide students and technical people with an essentially practical account of the non-parasitic, virus, bacterial, and fungus diseases of cultivated plants in Italy, and it achieves its object admirably. The author avoids academic discussion and theorizing, and the information given is accurate, up to date, and agreeably concise. The non-parasitic diseases are classified according to causes, bacterial diseases according to the symptoms, and fungus diseases under families and genera. Virus diseases are dealt with under hosts and comprise the least satisfactory part of the book. There are several introductory sections, including one on modern fungicides, with a compatibility table incorporated; a helpful and lengthy glossary; and a comprehensive index. The whole is illustrated by four original coloured plates depicting twenty-five diseases, and 190 photographs and drawings. The photography is reasonably good but scarcely does justice to the excellence of the text. Most of the diseases dealt with are common to many countries, and it is instructive to compare their relative importance and the emphasis given to them in Italy with the position, for instance, in the United Kingdom. W. G. MOORE

SOIL EROSION

The Conservation of Natural Resources, *by R. C. Haw. Pp.* 256. *Faber and Faber Ltd, London.* 1959. 30*s. net.*

The author is an instructor in soil and water conservation at the Domboshawa School in Southern Rhodesia, and he has had a wide experience of conservation problems in Central, East, and South Africa. His book opens with an eloquent and moving picture of the inroads of soil erosion that he has watched and the losses of fertile land that this entails. Natural erosion is one of the major factors in geological evolution, but in many places it is being accelerated by man's activities, and this can be largely avoided by better farming practices, as in the successful Tennessee Valley Authority experiment in the Mississippi Valley.

The present study differs from most of the books describing the ravages of soil erosion in that the greater part of it is devoted to the practical details of the techniques for conserving both soil and water. It has been written with the object of helping farmers to appreciate the methods by which soil erosion can be checked. Naturally, in a volume of this size the engineering and agricultural practices involved can be described only in outline, but the account of these is clear and convincing, and it is supplemented by a useful bibliography and an appendix dealing with the plants specially suited to soil conservation. The fruits of the author's experience are applicable over a much wider field, especially in the tropical and subtropical regions of the world, and farmers will find his book a most valuable guide. H. HARTLEY

BINARY ALLOYS

Constitution of Binary Alloys (*second edition*), *by M. Hansen, with the co-operation of K. Anderko. Pp. xix+1305. McGraw-Hill Book Co. Inc., New York; McGraw-Hill Publishing Co. Ltd, London.* 1958. £12 12*s. net.*

A knowledge of the appropriate phase diagram is a necessity in any investigation involving the properties of alloys, and few reference books can have been consulted more extensively than Hansen's *Der Aufbau der Zweistofflegierungen.* This comprehensive survey of information on binary diagrams was published in 1936 and has inevitably decreased in value, but no later compilation has effectively replaced its careful and critical assessment of data. An outstanding welcome from all metallurgists and many other scientists is thus assured for this second edition, which is a completely rewritten book.

Some idea of the problems facing the authors is given by the increase in the number of systems covered (1334 instead of 828), in phase diagrams reproduced (717 instead of 456), and in references consulted (9800 instead of 5500). This has necessitated a terser style of writing, and detailed comparisons of the relative merits of different investigations are no longer given, although great care has been taken to select and recommend the best data. Phase diagrams are now plotted with composition scales marked linearly in atomic percentages; non-linear weight percentage scales, and tables to facilitate rapid and accurate interconversion are also supplied; the diagrams are beautifully drawn and reproduced. The book is very highly recommended.

J. W. CHRISTIAN

METALLURGICAL DICTIONARY

A Dictionary of Metallurgy, *by A. D. Merriman. Pp. xv+401. Macdonald and Evans Ltd, London.* 1958. £6 6*s. net.*

The effort which has gone into 'A Dictionary of Metallurgy' is obviously quite considerable, painstaking, and reliable, but, having submitted some 50 current metallurgical terms to this 'dictionary' to test it, I formed the opinion that it would have been better termed a glossary. Furthermore, the book claims to be up to date and gives some examples from the nomenclature of atomic energy. Consideration of references to one of the newer metals, titanium, indicates that 1953 to 1954 was the dead-line in this field. It should be made clear as to how up to date the references are in the various metal fields. For research workers it is not encyclopaedic enough in its reviews, but for metallurgists it can be reasonably helpful on the mineral and extraction side. It should also be noted that little treatment is given to terms used in discussing theories of the metallic state on the one hand, or to metallurgical terminology connected with, say, modern melting techniques, rolling, jointing (particularly welding),

or X-ray examination on the other. Despite these limitations, some 7000 current words are covered.

The compilation of this book certainly justifies further intensive work with a view to producing a comprehensive encyclopaedia of metallurgical terms. For those very much on the outer fringe of metallurgy, who would like a first source of reference, it is useful, particularly because so far as I know there is no similar work available in the English language.

W. O. ALEXANDER

HISTORY OF SCIENCE

Patterns of Discovery, *by N. R. Hanson. Pp. ix+241. Cambridge University Press, London.* 1958. 30*s. net.*

In his introduction Professor Hanson states that 'the issue is not theory-testing but theory-finding', his concern 'is not with the testing of hypotheses, but with their discovery'. His book is thus a welcome break-away from the stream of studies inspired by the schools, whether of Wittgenstein or of Carnap, of philosophical analysis. Not that Hanson (or the reviewer) would for a moment deny the value of the clarification of the logical structure of existing knowledge which these studies have achieved; but by an over-emphasis of the hypothetico-deductive element in 'completed' systems they have, he implies, left out of account the structure of creative thinking. By an admirable study of the origins of terrestial and celestial kinematics at the hands of Galileo and Kepler respectively he introduces this missing element of the 'conceptual foundations'. Of the greatest importance in this part of his work is his demonstration, by argument and graphic illustrations, of the ambivalence of mere perceptual 'data' unless biased by a precedent interpretative scheme—a fact well known to psychologists, as he shows by an extensive range of references, but too often ignored by philosophers. The main part of the text concludes with an effective application of these views to the elucidation of the paradoxes and perplexities of the physics of elementary particles.

Professor Hanson writes with great gusto; every page challenges critical appreciation. Though it may be questioned how far the scope of the inquiry covers science, this is a book which no one whose interest in scientific endeavour extends beyond routine can afford to miss. The sixty pages of critical and bibliographical notes at the end reveal the prodigious industry of the author and provide a guided stimulus to further research by the reader.

W. P. D. WIGHTMAN

HISTORY OF TECHNOLOGY

A History of Technology, *Vol. IV.* The Industrial Revolution *c.* 1750–*c.* 1850, *edited by Charles Singer, E. J. Holmyard, A. R. Hall, and Trevor I. Williams. Pp. xxxiv+728. Clarendon Press, Oxford.* 1958. £8 8*s. net.*

This volume really marks the climax of the history of technology. During the century which it covers, technology, increasingly influenced by and influencing science, finally came to establish genuinely industrial societies. While the earlier volumes cast their net widely over the world, this one now draws it tightly round events in the West. Like its predecessors, it is made up of chapters on a variety of different subjects, as the material demands. Written by different experts, the chapters are grouped under larger headings. There are some 350 line drawings, 48 plates (of which many contain more than one illustration), and workable indexes of personal names, place-names, and subjects.

The first group of chapters, forming Part I, deals with primary production, and covers agricultural methods and machinery, fish preservation and whaling, and the mining and processing of coal, iron, and the non-ferrous metals. These chapters thus describe the primary means by which the rapidly rising populations of industrial countries were fed and clothed, and by which industry was supplied with what became its main source of energy—coal—and with the metals of which its machines and many of their products were made. Part II gives an account of the forms of energy exploited, attention being given to quantitative comparisons, and here is to be noted the considerable development of the water-mill, which was only slowly replaced by the improved designs of reasonably efficient steam-engines burning coal. Part III covers manufacture, and includes the rise of the early chemical industry (at first a mainly French achievement), the making of gas for light and heat, the textile industry, ceramics and glass, and the rapid improvement in the design and construction of precision instruments (essential for science as well as for accurate control of advanced industry) and machine tools. Part IV takes us into another part of the field, the application of the new industrial products and methods in the construction of buildings and bridges, especially of iron, and in the engineering of water supply and sanitation which the growth of large industrial towns made imperative. Part V moves on to communications—roads, canals, ships, cartography, dredging, and telegraphy. The volume is brought to a close by a brief essay on the change in character from technology based on the empirical crafts, as in the earlier volumes, to technology based on science, as it broadly was by the middle of the nineteenth century.

Two large historical issues are involved in the subject of this volume. The first is interaction between technology and science. Some indication is given of the scientific advances that influenced technology. (Here we may note the blemish that James Watt is wrongly said to have 'independently discovered the phenomenon of latent heat of steam'—page 182.) But considerations of space have entirely squeezed out any discussion of the second large historical issue, the relation of technology to economic and social structure and policy and to the demands of trade and war. Although they do get a brief treatment in the next, and final, volume, what is really required is that some historian should use the material supplied in these volumes to write a full analytical essay on these themes, at the same time relating the history of technology to the history of science and its institutions of education and research.

A. C. CROMBIE

Short notices of books

(These notices are descriptive rather than critical and are designed to give a general indication of the nature and scope of the books.)

Quantum Particle Dynamics, *by J. McConnell. Pp. xi+252. North-Holland Publishing Co., Amsterdam.* 1958. *40s. net.*

The aim of this book is to provide a background for those who have no previous acquaintance with relativity and quantum theory, so that they can gain sufficient knowledge of quantum and meson theory to understand the main features of the theory of elementary particles. The treatment is mathematical, but presumes no more than a working knowledge of calculus and of elementary algebra, and the book is intended for advanced students and research workers. It includes chapters on quantum theory, wave mechanics, matrix mechanics, the Dirac equation, nuclear forces, and mesons and nucleons.

Expansion Machines for Low Temperature Processes, *by S. C. Collins and R. L. Cannaday. Pp.* 116. *Clarendon Press, Oxford; Oxford University Press, London.* 1958. 12*s.* 6*d. net.*

There is in this book a brief description of the development of engines for refrigerative use, and chapters on engines and turbines for gas liquefaction, and on expansion engines in low-temperature systems; it is these engines that are in part responsible for the striking increase in research in low-temperature science. The book also deals with some applications of these machines.

Physics of Meteor Flight in the Atmosphere, *by E. J. Öpik. Pp. viii+174. Interscience Publishers Inc., New York; Interscience Publishers Ltd, London.* 1958. *Paper covers,* 15*s. net; bound,* 30*s. net.*

The phenomena occurring during the flight of a meteor through the terrestrial atmosphere are dealt with in this book, with the intention of providing a basis for further research. The subjects covered include the classification of meteors, meteoroid energy transfer, ablation, and atomic collisions. The last chapter mentions some applications, referring to the Draconids and the naked-eye meteors.

Free Radicals, *by A. F. Trotman-Dickenson. Pp. viii+142. Methuen & Co. Ltd, London; John Wiley & Sons Inc., New York.* 1959. 12*s.* 6*d. net.*

The greater part of this book concerns the quantitative aspects of elementary reactions involving radicals, although the whole field of free radicals is briefly surveyed, including the physical properties of free radicals, and the experimental methods used in their study. There is a chapter on the reactions of the biradicals.

Nouveau traité de chimie minérale, *edited by P. Pascal. Vol. XII, pp. xxxix+692; Vol. XIX, pp. xxxix+953. Masson et Cie, Paris.* 1958. *Vol. XII: paper covers, fcs.* 6000; *bound, fcs.* 7000. *Vol. XIX: paper covers, fcs.* 8500; *bound, fcs.* 9700.

Volume XII has chapters on vanadium by A. Morette, on niobium and tantalum by R. Rohmer and M. Foex, and a shorter section on protoactinium by G. Bouissières and M. Haïssinsky. The physico-chemical characteristics of the elements have become better known since the last edition, which has made possible their more systematic arrangement, and is has also become possible to eliminate some dubious compounds, and to show more fully the relationships between these elements and their neighbours in the Periodic Table.

Volume XIX—there are to be twenty volumes in all—is concerned with the six platinum metals. The section on ruthenium and osmium is by R. Charonnat, and G. Ciepka and P. Poulenc have written on rhodium. The articles on iridium by M. Delépine and on palladium and platinum by Cl. Duval are reprinted from the previous edition.

Endocrine Control in Crustaceans, *by D. B. Carlisle and Sir Francis Knowles. Pp. vii+120. Cambridge University Press, London.* 1959. 21*s. net.*

Certain body functions in crustaceans are controlled by chemical substances, manufactured by cells in the nervous system and elsewhere, that are carried by the blood-stream. This book discusses the studies that have marked significant advances in the knowledge of this endocrine control. An extensive list of references is included.

Einführung in die Vektorrechnung für Naturwissenschaftler und Chemiker, *by H. Sirk. Pp. xi+124. Verlag von Dr Dietrich Steinkopff, Darmstadt.* 1958. DM 16.

Many fields of science use vector mathematics, and this book is intended to provide a basic knowledge of this branch of mathematics. It starts from the fundamental principles and covers the elements of vector algebra and vector fields. Examples of the vectorial approach to problems in crystallography, chemistry, physics, and meteorology are included, together with some examples from electrocardiography.

Biographical Memoirs of Fellows of the Royal Society, *Vol. IV. Pp.* 359. *The Royal Society, London.* 1958. 30*s. net.*

Accounts are given of the lives and achievements of twenty-seven Fellows who died during 1957–58. Each memoir is preceded by a full-page photograph and followed by a bibliography of the deceased Fellow's published works.

Le Leggi della Vita, *edited by G. Enriques, E. Macorini, and G. Pampaloni. Pp.* 687. *Nicola Zanichelli Editore, Bologna.* 1959. *Lire* 5800.

This volume forms part of a series of general biological works, and is a copiously illustrated semi-popular encyclopaedia of biology comprising general articles by various contributors on the discovery of the living world, cytology, the biological functions of organisms, environment and life, animal behaviour, and control in biology. One section provides a chronology of the biological sciences, general tables and diagrams of biological interest, and a 193-page dictionary of biological terms.

Gli Atomi e la loro Energia, *by E. Persico. Pp. xvi+490. Nicola Zanichelli Editore, Bologna.* 1959. *Lire* 5500.

The book contains two sections, the first covering atomic physics and the second nuclear physics. The treatment is essentially theoretical, but acquaintance with mathematics beyond elementary differential and integral calculus is not required. The introductory chapters deal with the Bohr-Sommerfeld theories of the atom, leading up to modern views of quantum and wave mechanics. The nuclear physics section discusses the basic phenomena of radioactivity and gives an account of recent applications of nuclear fission.

Notes on contributors

H. C. VAN DE HULST,
Ph.D.,

Was born in Utrecht, Netherlands, in 1918 and received his doctor's degree at Utrecht University in 1946, and is now professor of astrophysics at Leiden University. Has published 'Light scattering by small particles' and many articles on astronomical subjects, dealing with the solar corona, the zodiacal light, interstellar dust, the interstellar gas, and radio-astronomy. He received the Henry Draper Medal and the Eddington Medal for his prediction of the 21-cm line and for his work in this field with the Leiden group.

J. W. ATZ,
B.A., M.Sc., Ph.D.,

Was born in 1915 and educated at Cornell and New York Universities. He joined the staff of the New York Aquarium, New York Zoological Society, in 1937 and has worked for that institution ever since, with the exception of nearly six years' military service with the United States Army. He was appointed Assistant Curator in 1947 and Associate Curator in 1957.

G. E. PICKFORD,
Ph.D.,

Was born in England in 1902. After leaving the University of Cambridge she spent three years as Mary Ewart Travelling Scholar, studying earthworms in South Africa. She went to Yale University and submitted a monograph on this subject as a doctoral thesis (1931). In 1934 she joined the staff of the Bingham Oceanographic Laboratory at Yale and has been associated with this institution ever since, and she was appointed Research Associate in 1946. She taught at Albertus Magnus College, New Haven, Conn., from 1934 to 1948. She studied Octopoda from various parts of the world, and has published several papers on the subject, on the Vampyromorpha, an archaic group of deep-sea cephalopods. She began experimental work on fish endocrinology in 1947 and has specialized in this field during the past twelve years.

C. R. AUSTIN,
D.Sc., B.V.Sc.,

Was born in 1914 in Sydney, Australia, and educated at Eastbourne College, England, and Sydney University. He was a member of the research staff of the Commonwealth Scientific and Industrial Research Organisation, Australia, from 1938 to 1954, investigating biochemical aspects of pregnancy toxaemia in sheep, the development of special operational and emergency rations for troops, and the physiology of reproduction. He joined the research staff of the Medical Research Council, England, in 1954. He is currently engaged in research on mammalian fertilization and associated phenomena. He has been a Secretary of the Society for Endocrinology since 1956.

E. C. AMOROSO,
Ph.D., M.B., B.Ch., B.A.O., F.R.S.,

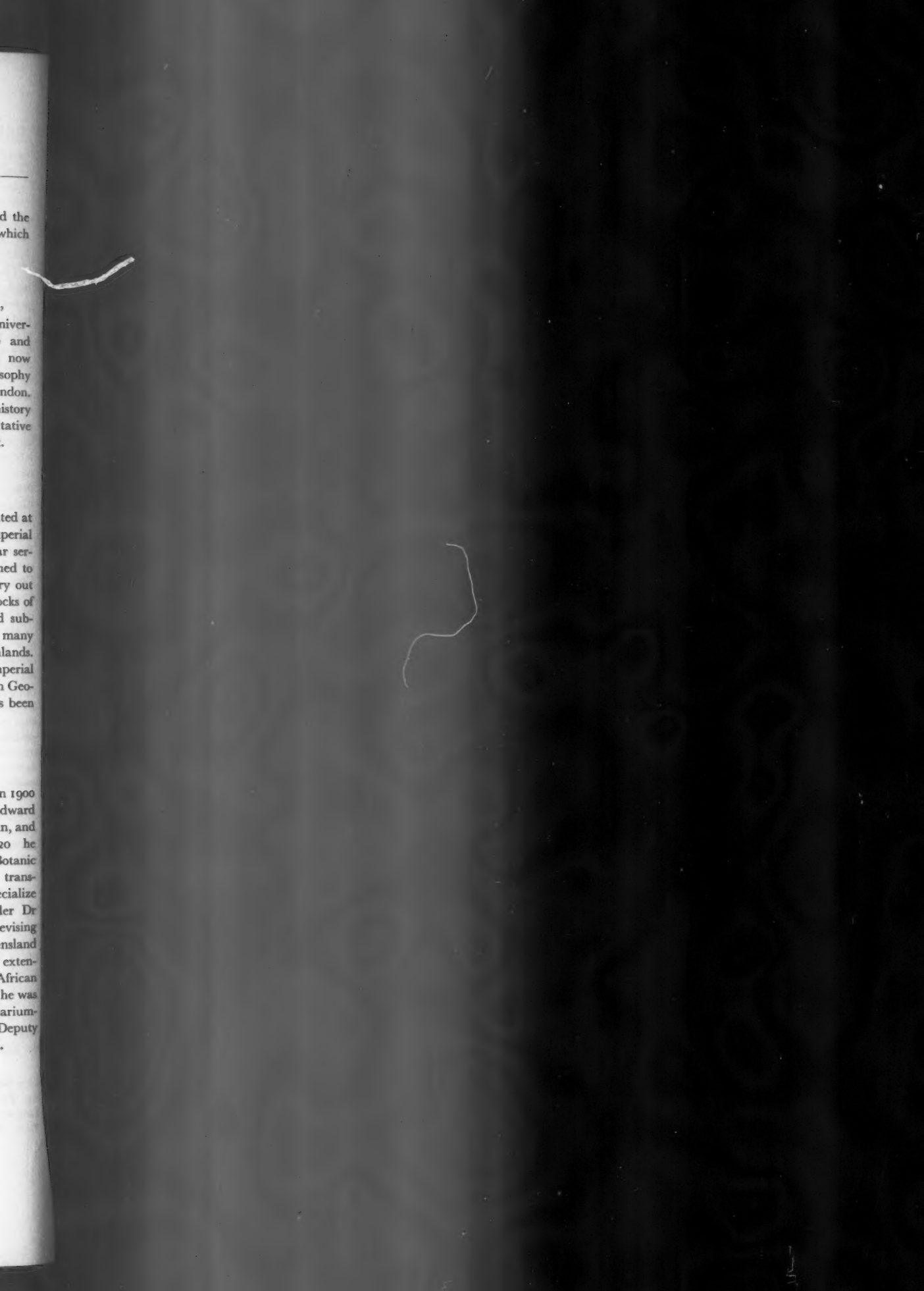
Graduated in medicine at University College, Dublin, and studied at the *Kaiser Wilhelm Institut für Zellforschung*, Berlin, the University of Freiburg, and University College, London. In 1929 he was awarded the McArdle Medal in Surgery and a travelling fellowship in science at the National University of Ireland. He was appointed to the Royal Veterinary College, University of London, in 1935, and has been Professor of Physiology since 1948. His main interest in research is the structure and function of the placenta, and the physiology of reproduction, on which he has published extensively.

D. McKIE
Ph.D., D.Sc., F.R.I.C., F.R.S.E.,

Was born in 1896. He entered University College, London, in 1920 and graduated in chemistry, and is now Professor of the History and Philosophy of Science in the University of London. He has written extensively on the history of chemistry, including an authoritative book on Lavoisier's life and work.

J. SUTTON,
Ph.D., F.G.S.,

Was born in 1919 and was educated at King's School, Worcester, and Imperial College, London. Following war service as a radar officer, he returned to Imperial College in 1947 to carry out research on the Pre-Cambrian rocks of Loch Torridon. He has worked subsequently on crystalline rocks of many other parts of the Scottish Highlands. In 1948 he joined the staff of Imperial College, was appointed Reader in Geology in 1956, and since 1958 has been Professor of Geology.

C. E. HUBBARD,
O.B.E., F.L.S.,

Was born in Appleton, Norfolk, in 1900 and was educated at the King Edward VII Grammar School, King's Lynn, and Chelsea Polytechnic. In 1920 he started work at the Royal Botanic Gardens, Kew, subsequently transferring to the Herbarium to specialize on the *Gramineae* (grasses) under Dr Otto Stapf. He spent 1930–31 revising the grass collections of the Queensland Government. He has published extensively, mainly on the British, African and Australian grasses. In 1957 he was appointed Keeper of the Herbarium-Library, Kew, and became Deputy Director of the Gardens in 1959.